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AN OVERVIEW OF PHOSPHORUS, NITROGEN AND ORGANIC CARBON OF MANITOBA INTERJURISDICTIONAL RIVER SITES, 1970-1979

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ABSTRACT

Spatial patterns and annual cycles of phosphorus, nitrogen and organic carbon for the interjurisdictional boundary waters of Manitoba are summarized for the period 1970 to 1979. Chemical species partitioning for each site for 1978 and 1979 are also considered. The data base is assessed for consistency and completeness.

Mean annual concentrations of phosphorus, nitrogen and organic carbon vary greatly among sites, although the river systems can be grouped into two main regions; the Palaeozoic-Mesozoic Region generally characterized by highly productive agricultural land, and the Pre-Cambrian Region consisting of shallow soils, bogs and forests in the northern and eastern part of the province. The former is generally characterized by higher and greater year to year variability in nutrient concentrations. Most rivers of the Palaeozoic-Mesozoic Region exceed the objectives of 0.05 mg/L and 1.0 mg/L total phosphorus and total nitrogen respectively.

Rivers of the Pre-Cambrian Region show a general lack of seasonal variability. Although not entirely consistent, rivers of the Palaeozoic-Mesozoic Region are characterized by maximum total phosphorus concentrations coincident with spring high flows, maximum total nitrogen concentratins during the winter season and total organic carbon peaks during the spring and/or fall. This Regional pattern is not apparent in the river nutrient loadings due to the dominance of flow in the large river systems of the Pre-Cambrian Region.

The partitioning of total phosphorus and nitrogen between dissolved and particulate species only partially addresses the nutrient availability question due to the need to consider the proportion of the particulate species which is biologically available. Dissolved phosphorus is dominant in most rivers of the Palaeozoic-Mesozoic region while the rivers of the Pre-Cambrian region have an essentially equal distribution of the two species. Dissolved nitrogen is the dominant nitrogen form in all rivers. Similarly, dissolved organic carbon, probably largely allochthonous in origin is the dominant carbon form. The lowest ratios of dissolved to particulate carbon are noted for the Red and Saskatchewan Rivers.

Trends have not been considered for this data set. This would require more intensive assessments of seasonal variability in weather conditions as well as data base variability among sites and between years. Addition of data collected by non-federal agencies, and the extension of this type of assessment to the river systems of the Canadian plains is recommended for more in-depth interpretation.

RESUME

On présente en résumé les profils géographiques et les cycles annuels du phosphore, de l'azote et du carbone organique pour les eaux limitrophes interjuridictionnelles du Manitoba pour 1970 à 1979. Le partage des espèces chimiques pour chaque point, pour 1978 et 1979, est aussi examiné. La base de données est évaluée afin d'établir si les données sont cohérentes et complètes.

Les teneurs annuelles moyennes en phosphore, en azote et en carbone organique diffèrent grandement d'un point à l'autre, même si les bassins hydrographiques peuvent être groupés en deux grandes régions, à savoir la région paléozoique-mésozoique, caractérisée par des sols agricoles très productifs, et la région précambrienne, où l'on retrouve des sols minces, des marécages et des forêts dans le Nord et l'Est de la Province. Dans la première région, la variabilité d'année en année des teneurs en substances nutritives est, de façon générale, plus élevée et plus importante. Dans la plupart des rivières de cette région, les teneurs maximales totales en phosphore et en azote, respectivement de 0,05 mg/L et de 1,0 mg/L, sont dépassées.

Les rivières de la région précambrienne ne présentent pas, de façon générale, de variabilité saisonnière. En fait, même s'il y a des variations, les rivières de la région paléozoique-mésozoique sont caractérisées par la présence des teneurs maximales totales en phosphore au printemps, au moment de la crue, et des teneurs maximales totales en azote surtout en hiver, les pointes dans le cas du carbone organique total survenant soit au printemps ou à l'automne. Ce profil régional n'est pas manifeste dans les teneurs en substances nutritives des rivières à cause de l'importance de l'écoulement dans les grands réseaux hydrographiques de la région précambrienne.

Le partage des charges totales de phosphore et d'azote sous forme dissoute et sous forme solide ne se rapporte pas totalement à la présence de substances nutritives puisqu'il faut prendre en compte la proportion de ces substances sous forme solide qui est présente biologiquement. Le phosphore dissout domine dans la plupart des rivières de la région paléozoique-mésozoique tandis que le partage entre les deux formes est essentiellement égal dans les rivières de la région précambrienne. L'azote, sous sa forme dissoute, domine dans toutes les rivières. De même, le carbone organique dissout, probablement d'origine allochtone, en grande partie, est la forme dominante de carbone. Les rapports de carbone dissout et solide les plus bas sont relevés surtout dans les eaux de la Rouge et la Saskatchewan.

Pour cet ensemble de données, aucune tendance n'a été étudiée; il faudrait des évaluations plus poussées de la variabilité saisonnière des conditions atmosphériques ainsi que de la variabilité de la base de données d'un point à un autre et d'une année à l'autre. D'autres données recueillies par des organismes extérieures au gouvernement fédéral devraient être ajoutées et ce type d'évaluation devrait être appliquée aux bassins hydrographiques des Plaines canadiennes pour permettre des interprétations plus approfondies.

INTRODUCTION

Eutrophication is a natural aging process of lake systems. It is synonomous with increased growth rates of the biota of lakes. In essence, over a long period of time, a lake fills with sediment from rivers and streams draining its watershed, from the decaying biota of the lake, and, to a lesser extent, from precipitation and dustfall directly onto its surface. On a geological timescale, the effect of this process is that a lake will presumably cease to exist. Man's activities within a drainage basin can alter this natural process and accelerate it to a human, rather than a geological time scale. This latter phenomenon is commonly referred to as 'cultural' eutrophication to distinguish it from the natural aging process.

Cultural eutrophication is caused by excessive loads of aquatic plant nutrients to natural waters. This can result in nuisance growths (i.e., growths that interfere with man's use of the water) of algae and higher aquatic plants. The plant growths and associated changes in water quality can also cause significant changes in aquatic plant and animal populations. All of these changes can hinder the use of the water for domestic and industrial water supplies, for irrigation and for recreational pursuits. Excellent reviews of the problem are contained in American Water Works Association (1966); Fruh (1967); Stewart and Rohlich (1967); Vollenweider (1968); Lee (1971); and Vallentyne (1974).

Although some lakes are naturally eutrophic, an increased nutrient load to a water body has most often been associated with an intensification of human activity within the drainage basin. Large urban centres with their resultant municipal sewage effluents and associated high nutrient loads have traditionally been the most apparent source. In many areas, however, agricultural activities (both livestock and crop production) can be major sources of nutrients to water bodies. Obviously, the degree of development within a drainage basin, whether it is residential, industrial or agricultural, is a primary determinant in assessing the impact of cultural eutrophication.

Since man is so heavily dependent upon fresh water, the trophic state (i.e. degree of eutrophication) of a water body is a major consideration in determining its suitability for use. This is especially true in essentially water short areas, such as Canada's prairie provinces.

As a result of the obvious requirement for water of good quality for most municipal, industrial, agricultural and recreational needs, the Water Quality Branch (WQB) conducts a program to measure and assess water quality in Canada. Nutrient analysis and related quality indicators comprise a major component of this program. Within the Manitoba District of the Western and Northern Region, WQB's routine sampling is generally conducted at international and interprovincial river sites and other waters in which there is significant federal interest. The interjurisdictional sites are considered in this report. Included are 23 rivers at 24 interjurisdictional sites (Figure 1). These sites include all major incoming (20) and outgoing (4) rivers in Manitoba (Churchill River has two sites). Although nutrient data are available for some of these rivers prior to 1970, this report considers only the 1970-1979 period.

The objectives of this report are:

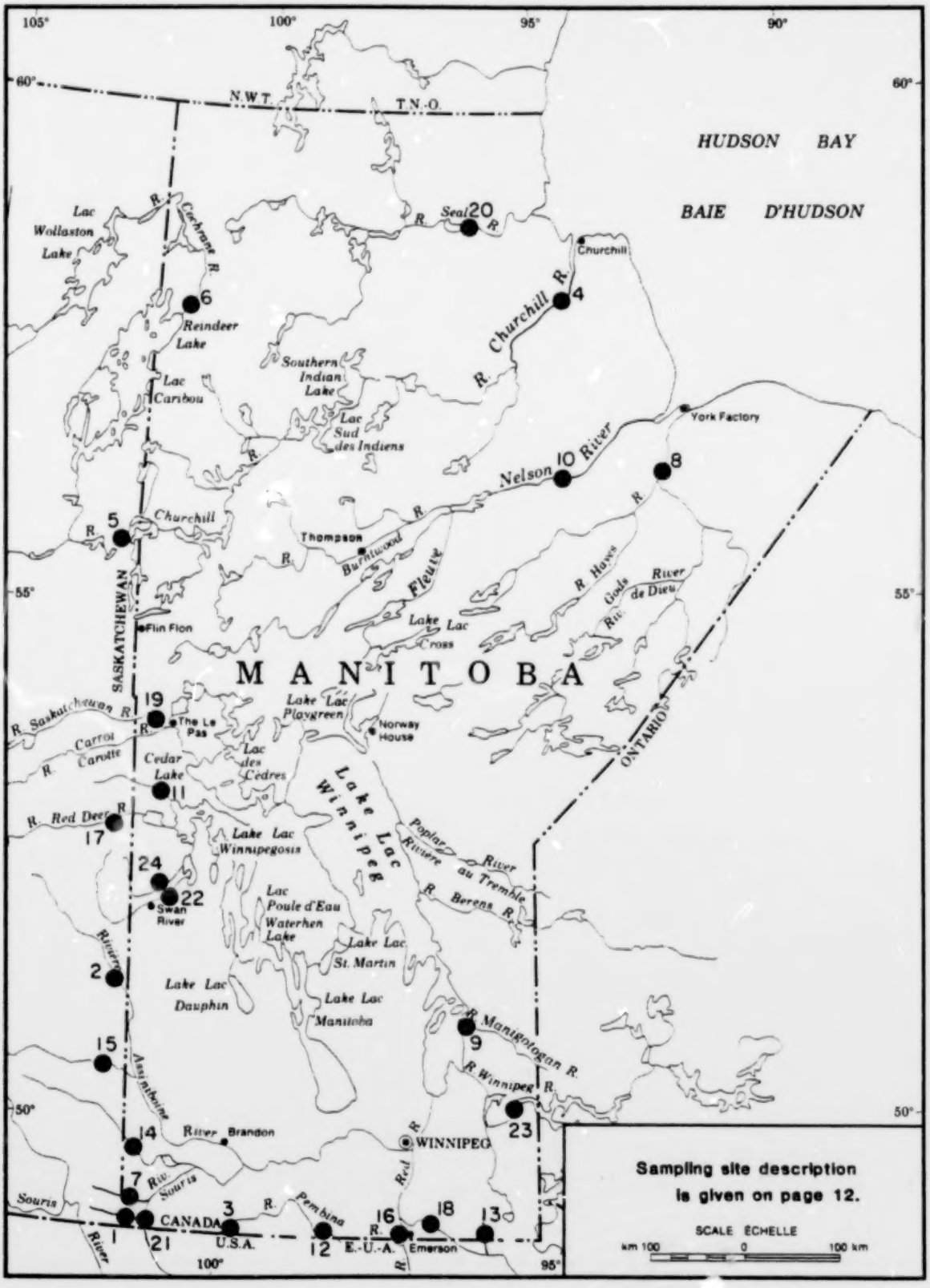
(i) To provide a summary and overview of the WQB phosphorus, nitrogen and organic carbon data available for transboundary water sites in the province of Manitoba with respect to spatial patterns and annual cycles;

(ii) To discuss these patterns and cycles in the context of gross drainage basin characteristics, including geology, soils, land use and other factors;

(iii) To evaluate these data with respect to problems, completeness and inadequacies; and

(iv) To present the findings of this historical data review in a manner which will extend the basic understanding of nutrient water quality to a wide audience including the public, resource planners and managers, and scientists of related disciplines.

Figure 1. Interjurisdictional Sampling Sites



INDICATORS OF INTEREST

Phosphorus, nitrogen, carbon, hydrogen, oxygen, sulfur and many other elements are essential for animal and plant growth. The higher proportions of phosphorus and nitrogen necessary for sustaining plant life relative to other elements means that these elements are frequently referred to as macronutrients. Carbon, itself, is only infrequently a limiting nutrient. However, organic carbon, a product of photosynthesis, is a useful indicator of the productivity of surface water in response to nutrient availability. This report focuses on nitrogen and phosphorus and organic carbon.

(i) Phosphorus

The environmental interest in phosphorus stems from its major role in biological metabolism and the relatively small amounts of phosphorus in the aquatic system naturally. Biological productivity rates of many lakes are controlled to a large extent by the rate of phosphorus cycling in relation to the input loading of phosphorus from external sources (Wetzel, 1975).

Traditionally, the most important quantity in view of the metabolic characteristics of a water body is the total phosphorus (TP) concentration. TP consists of phosphorus in suspension in particulate matter, and phosphorus in dissolved form. Particulate phosphorus includes phosphorus in organisms, dead particulate organic matter, mineral, mineral phases of rock and soil, or macro-organic aggregations. It is also found adsorbed into inorganic particles. The dissolved inorganic phosphorus fraction is composed of orthophosphate, polyphosphates and organic colloids.

Recently, the importance of the biological availability of the particulate phosphorus in conjunction with the dissolved inorganic fraction has received considerable attention. The percentages of biologically available phosphorus vary between point and diffuse sources,

lake basins and streams, as well as from season to season. In systems where the particulate phosphorus fraction is very high (30 to 40% of TP), an assessment of its availability through chemical fractionation and/or bioassay techniques is essential to understand the significance of loading information.

For the period considered herein, the data base is largely restricted to TP. The exception is the 1978-79 data for which additional phosphorus speciation data are available and are discussed. The bio-availability of the particulate phosphorus fraction has not been assessed as part of this monitoring program.

(ii) Nitrogen

Nitrogen accounts for 78% by volume of the atmosphere. Soils, plants and ground water also may contain high concentrations of nitrogen. Environmentally, nitrogen tends to be much more readily available naturally in aquatic systems than phosphorus. Natural sources of nitrogen include direct precipitation to the lake surface, nitrogen fixation by bacteria both in the water and the sediments, nitrogen fixation by algae and finally, inputs from surface and groundwater drainage. Man's activities can considerably influence the magnitude of the nitrogen loading to an aquatic system from any one of these major sources.

Nitrogen occurs in fresh waters in numerous forms, including dissolved molecular N_2; a large number of organic compounds ranging from amino acids and amines to proteins and refractory humic compounds of low nitrogen content; ammonium (NH_4+); nitrite (NO_2) and nitrate (NO_3) (Wetzel, 1975).

The natural abundance of nitrogen in the aquatic system combined with increased nitrogen due to cultural activities means that nitrogen is less frequently a limiting nutrient which can ultimately restrict vegetative growth. Consequently, managerial responses to culturally induced

nutrient enrichment (eutrophication) has tended to focus on the control of phosphorus. Nitrogen has, however, been retained as an essential element of the monitoring program. As with phosphorus, emphasis will be on total nitrogen (TN), although information for selected species will be evaluated for 1978-79.

Concentrations of certain nitrogen forms, in particular ammmonia, can be of environmental concern independent of the eutrophication issue. Ammonia concentrations of natural surface waters seldom exceed 0.1 mg/L. At low concentrations, ammonia is not generally considered to be toxic to man, animals or fish, but in alkaline conditions, concentrations as low as 0.01 mg/L may be harmful to freshwater aquatic life (United States Environmental Protection Agency, 1973). Generally, ammonia is readily oxidized to nitrite (NO_2) and nitrate (NO_3) which can subsequently be converted by bacteria to elemental nitrogen and returned to the atmosphere.

(iii) Organic Carbon

Carbon cycling within an aquatic system is complex and depends on a number of factors including CO_2 content of the air, lake trophic state and alkalinity. The most important nutrient form of carbon is usually inorganic. The concentration of inorganic carbon in fresh waters depends on the pH, which is controlled by the drainage basin characteristics. Since carbon is infrequently a limiting nutrient, monitoring of inorganic carbon is of limited value.

Biochemical decomposition of dissolved and particulate organic matter consumes oxygen within the aquatic system. Decomposition of excessive amounts of organic matter can lower oxygen levels below that required by aquatic organisms. Consumption of all of the oxygen in the water column (anoxia) can have significant effects on the biogeochemical processes in the system. For example, anoxic conditions can result in the release of biologically available mercury and phosphorus from sediments. Organic

carbon is an essential energy source to the aquatic metabolism. It may also serve as a transport mechanism of toxic substances and nutrients. The dissolved organic carbon (DOC) of streams is about 10 times that of the particulate form (POC). The amounts of DOC and POC reaching an aquatic system and the nature of these compounds vary with the seasons, the growth and decay cycles of the terrestrial and marsh vegetation through which runoff flows, and other factors, especially climatic ones (Wetzel, 1975). It is for all of these reasons that organic carbon is important in the aquatic ecosystem. Organic carbon varies from a few milligrams to 30 mg/L in surface water (McNeely et al., 1979). As with nitrogen and phosphorus, emphasis in the monitoring program has been upon total organic carbon (TOC). DOC and POC will only be assessed for 1978-79.

DRAINAGE AREA CHARACTERISTICS

The natural characteristics as well as man's use of the drainage basin are important factors in determining the nutrient quality of a fluvial system. Specifically, the bedrock geology, surficial geology, land use, as well as climate and vegetation must be considered. Since this report is concerned with the nutrient quality at the international and interprovincial sites, a very large, complex drainage area is involved (Figure 2). Only a brief summary of these characteristics is possible here.

(i) Bedrock and Surficial Geology

The northern and eastern region of the Province of Manitoba rest on the geologically ancient Pre-Cambrian Shield (Figure 2). Although granitic rock outcrops are extensive throughout this region, large areas are covered by thick deposits of glacial drift. The soils are mostly composed of subarctic brown, subarctic podzol (white or grey soil), organic and peat-bog type soils (Allan and Williams, 1978).

Figure 2. Simplified Geology for the Drainage Basins.

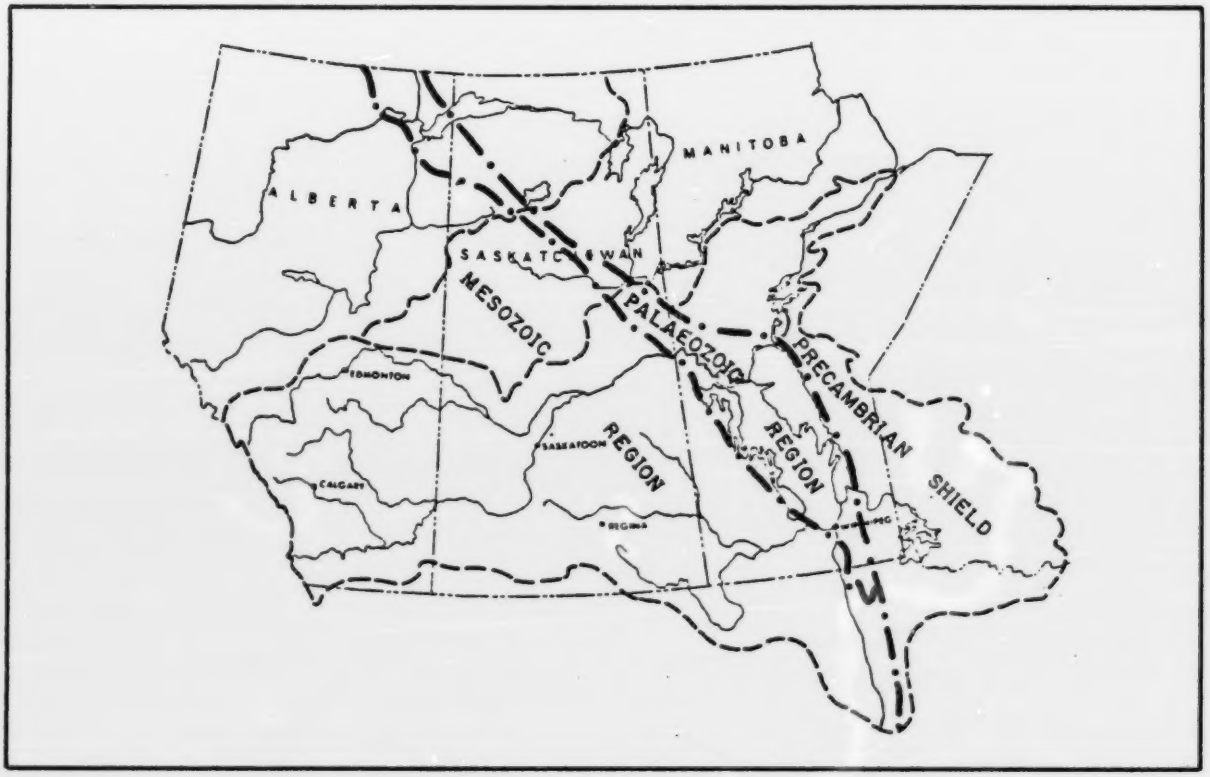
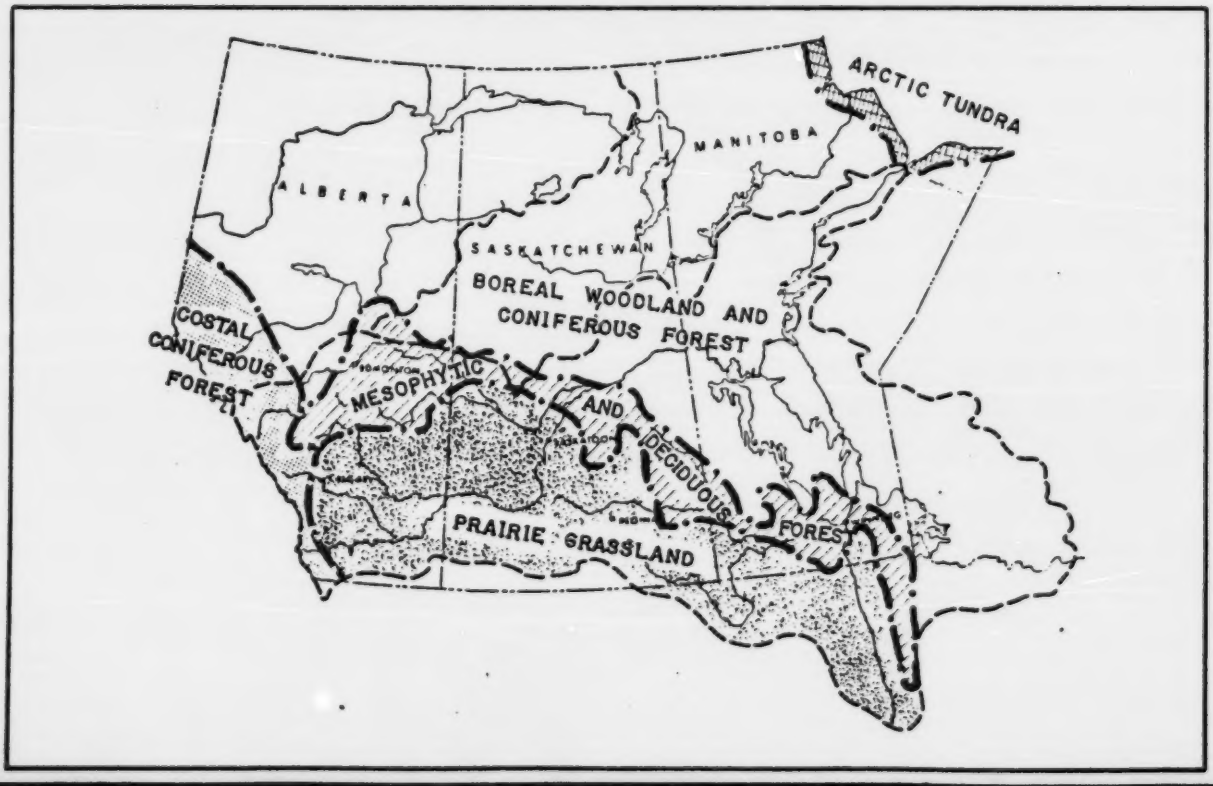


Figure 3. Vegetation Pattern for the Basin.



Around the central part of the Province, the low lying interlake area of Lake Winnipeg, Lake Manitoba and Lake Winnipegosis and a narrow strip of land west of it are characterized by shallow soils underlain by Palaeozoic rocks. The south and south-west parts of Manitoba are underlain by carbonate rocks of the Mesozoic age and pleistocene morainal (glacial) deposits. Silt and clay deposits mostly from the Wisconsin glaciation and Lake Agassiz form top layers of this region. The brown forest soil and the deep dark soil found here are developed from a ixture of humus material with fine silt and clay. Overall, the soils of the Mesozoic Region are nutrient rich and further enriched by ongoing fertilization and cultivation (Allan and Williams, 1978).

(ii) Vegatation and Land Use

Vegetation and land use vary greatly from north to south (Figure 3). Tundra characteristics (lichen floor and scattered conifers) exist in the extreme northern part of the Province. Major portions of the Hayes, Churchill and Nelson River basins are covered by boreal forest (predominantly needle-leaf trees). The Le Pas area, the interlake area and eastern Manitoba are also boreal forest areas with some broad leaf trees and willows. A mixture of grasslands, aspen and broad leaf parklands with some interspersing of boreal forests cover the Southern and Southwestern area.

Land use is also highly variable throughout the drainage basin. Mining activities occur in northern Manitoba and Saskatchewan while gas and oil production is scattered throughout Alberta and Saskatchewan. Forest harvesting occurs in the northern parts of all three provinces. More important in terms of the nutrient concentrations of the river systems is the extensive agriculture of the central and southern parts of the provinces. Land drainage of naturally nutrient rich soils may be increased in quantity and nutrient concentration through certain tillage and livestock related farming practices. Municipal and industrial effluent discharges to the rivers of the more populated south also contribute nutrients.

(iii) Climate and Precipitation

The climate is moderately dry with sharp seasonal temperature changes. The temperature varies greatly from south to north. Summers are hot but winters are long and cold with snow cover lasting from November to May in the north and shorter periods in the south.

Average annual precipitation (rain and snow) is about 500 mm. Total annual precipitation varies considerably from year to year. On average, 25% of the total annual precipitation arrives as snow in the south, increasing to 40% in the north. The south and south-west part of the Province and the adjacent regions of Saskatchewan and Alberta which constitute much of the Saskatchewan-Nelson River drainage basin are water short with periodic drought. Annual precipitation in this region ranges from 300 to 600 mm, generally increasing in an easterly direction. Generally, evaporation during the summer exceeds precipitation so that the soil moisture and the volume of river discharges are dependent on the winter snowfall and subsequent spring melt (Fisheries and Environment Canada, 1977).

METHODOLOGY

(i) Field Procedures

A majority of the samples considered in this report were collected as part of the routine sampling program by the WQB staff and the staff of the Water Resources Branch (WRB), in accordance with the procedures described in the WQB sampling manuals (Environment Canada, 1973; Water Quality Branch, 1979). Samples were collected in a well-rinsed 2 L polyethylene bottle affixed to a metal holder, allowing the bottle to fill as it sank at a constant rate. Samples collected using this technique are termed depth-integrated samples and the data generated describe the water quality at a particular site instantaneously. This report also includes results obtained from short-term intensive studies,

namely the Qu'Appelle River Basin Study, Souris River Basin Study, Lake Winnipeg-Nelson River Study, Manitoba heavy metal study and the Red and Souris Rivers nutrient studies. All except the Red and Souris River nutrient studies followed the WQB sampling procedures. In the Red and Souris River nutrient studies, an automatic sampler was used to provide a minimum of one sample per day. Sampling practices during the period under consideration are summarized in Table 1.

Samples for nutrient analyses, except for TP, were collected and transported in polyethylene bottles. Polyethylene bottles were used for TP until 1975. Subsequently, glass (sovirel) bottles were used for transporting the samples. This change was introduced to prevent adsorption of particulate matter to the polyethylene bottle walls. Although it is impossible to quantify the effect of this bottle change, it is suspected that the TP results reported prior to this time were somewhat lower than the actual values. No internal preservation was added to any of these samples, but for the most part, the samples were shipped in ice-packed containers. The shipping and storage time between sample collection and analysis varied considerably, with the northern sites experiencing greater delay. Samples collected with the automatic sampler were kept refrigerated until they were removed weekly.

(ii) Laboratory Procedures

The samples were analyzed at the Branch laboratories either at Calgary or Yellowknife, in accordance with analytical procedures described in the departmental methods manuals (Environment Canada, 1974; Environment Canada, 1979). Variations to these methods were introduced from time to time, and the precise method used in each analysis is summarized in the NAQUADAT dictionary (Environment Canada, 1983). The NAQUADAT parameter code, applicable time period and detection limits are presented in Table 2.

Table 1: Summary of Nutrient Monitoring Activities by Sites

Map Location	Sampling Site	Sampling Agency	Frequency of Routine Sampling	Period of Sampling
1	Antler River at Hwy 251	WQB, WRB Special study[1]	Quarterly[2] to 73 Monthly 73-79	70/01 - 79/12
2	Assiniboine River below Kamsack	WQB Special study	Quarterly to 73 Monthly 73-79	70/01 - 79/12
3	Badger Creek at Cartwright	WQB, WRB Special study	Quarterly to 74 Monthly 74-79	72/02 - 79/12
4	Churchill River above Red Head Rapids (RHR)	WRB Special study	Quarterly	72/09 - 79/12
5	Churchill River below Wasawakasik (W)	WQB	Monthly	74/06 - 79/12
6	Cochrane River near Brochet	WRB Special study	Quarterly	72/04 - 79/12
7	Gainsborough Creek at Hwy 83	WQB, WRB Special study	Monthly	73/03 - 79/12
8	Hayes River Below God's River	WRB	Quarterly	74/06 - 79/12
9	Manigotagan at Hwy 304	WQB, WRB Special study	Quarterly to 78 Monthly 78-79	70/01 - 79/12
10	Nelson River at Kettle Crossing	WRB Special study	Quarterly to 78	72/07 - 78/03
11	Overflowing River at Hwy 10	WQB, WRB	Quarterly to 78 Monthly 78 - 79	74/04 - 79/12
12	Pembina River near Windygates	WQB, WRB	Quarterly to 74 Monthly 74 - 79	70/01 - 79/12
13	Pine Creek Diversion at Hwy 89	WQB, WRB	Quarterly to 74 Monthly 74 - 79	72/09 - 79/12
14	Pipestone Creek at Hwy 255	WQB, WRB	Quarterly to 78 Monthly 78 - 79	74/08 - 79/12
15	Qu'Appelle River south of Welby[3]	WQB Special study	Monthly	70/01 - 79/12
16	Red River at Emerson	WQB, WRB Special study	Quarterly to 72 Monthly 72 - 79	70/01 - 79/12
17	Red Deer River at Erwood	WQB	Quarterly to 74 Monthly 74 - 79	70/01 - 79/12
18	Roseau River at Gardenton	WQB, WRB	Quarterly to 73 Monthly 73 - 79	70/01 - 79/12
19	Saskatchewan River above Carrot River[4]	WQB, WRB Special study	Quarterly to 72 Monthly 72 - 79	70/01 - 79/12
20	Seal River below Great Island	WRB Special study	Quarterly	72/08 - 78/12
21	Souris River near Coulter	WQB, WRB Special study	Quarterly to 73 Monthly 73 - 79	70/01 - 79/12
22	Swan River at Hwy 10	WQB, WRB	Quarterly to 78 Monthly 78 - 79	74/04 - 79/12
23	Winnipeg River at Point DuBois	WQB, WRB	Quarterly to 78 Monthly 78 - 79	72/07 - 79/12
24	Woody River at Hwy 10	WQB, WRB	Quarterly to 78 Monthly 78 - 79	74/04 - 79/12

1 - Refers to one of the short term intensive studies conducted under projects such as Qu'Appelle Basin Study, Souris River Basin Study, Lake Winnipeg Nelson River Study, Manitoba heavy metal study and Red and Souris River Nutrient study.
2 - Sampled four times per year or at time of visit.
3 - Samples were collected at St. Lazare until 1975.
4 - Samples were collected at The Pas until 1974.

TP was determined by direct analysis. When total dissolved phosphorus (TDP) and particulate phosphorus (PP) were required, analyses for TP and TDP were carried out and PP was calculated from the difference of these measurements. In 1975, improved analytical technique reduced the detection limit from 0.005 mg/L to 0.003 mg/L (Table 2). However, the TP concentration in most samples was well above even the higher detection limit and thus the change did not affect comparison of the pre and post 1975 data. The less than detection values were fewer than 0.2% of the observed values.

Until April 1978, TN was determined by adding Kjeldahl-N and nitrate and nitrite-N. Beginning in April 1978, TN was obtained by adding total dissolved nitrogen (TDN) and particulate nitrogen (PN). Both of these methods are recognized to be satisfactory methods in the determination of TN. However, the latter method is preferred when analyzing low concentrations because of the lower detection limits (Table 2). The less than detection values were mostly observed for nitrate and nitrite-N and these values were always an order of magnitude lower than the Kjeldahl-N values. Thus the TN values were not greatly affected by the less than detection values of nitrate and nitrite-N. The detection limit for Kjeldahl-N changed, from 0.5 mg/L to 0.1 mg/L in 1974 with a corresponding decrease in the number of less than detection values observed.

TOC was also determined in two ways. Until April 1978, direct analysis was used. From April 1978 on, TOC was obtained by adding dissolved organic carbon (DOC) and particulate organic carbon (POC). Both of these methods are recognized to be satisfactory methods in the determination of the TOC and the results are assumed to be comparable for the purposes of this report.

TOC values were always well above the detection limits. N and P values less than detection limit were interpreted as the detection limit value throughout this report.

Table 2: Analytical Method Codes and Detection Limits

Parameter	NAQUADAT Code	Applicable Time Period	Detection Limits mg/L
TP	15413	1970 - 75	0.005
TP	15406	1975 - 79	0.003
TDP	15103	1975 - 79	0.003
Kjeldahl-N	07001	1970 - 74	0.5
Kjeldahl-N	07002	1974 - 78	0.1
Kjeldahl-N	07003	1973 - 75	Not available
Nitrate-nitrite-NO_3	07103	1970 - 74	0.01
Nitrate-nitrite-N	07105	1970 - 74	0.005
Nitrate-nitrite-N	07106	1970 - 76	0.001,0.01,0.05
Nitrate-nitrite-N	07110	1974 - 79	0.01
TDN	07651	1978 - 79	0.01
PN	07902	1978 - 79	0.01
TOC	06001	1970 - 78	0.5
TDOC	06104	1978 - 79	0.1
TDOC	06101	1978 - 79	0.5
POC	06902	1978 - 79	0.01

(iii) Data Synthesis

Varying frequency in sampling and the different time periods in which the samples were collected (Table 1) resulted in considerable variability with respect to the amount of data for each site. Generally, the continually flowing rivers of the southern region had more data than ephemeral rivers and rivers of the north. For example, the number of samples for a given year varied from fewer than 3 to over 400. Three was chosen as the minimum number of samples necessary for most statistical manipulations. Many of the quarterly sampled rivers and seasonally flowing rivers had only 3 samples in certain years. There were a number of sites with less than 3 values per year but these were not included. The exception to this was the monthly comparisons of nutrient species data for 1978 and 1979 where all available data were considered for specific sites.

In certain cases, it is worthwhile to summarize differences and compare sites using mean annual concentrations. Due to the varying sample frequencies among years at the same site (e.g. the number of samples annually for the Red River ranged from 12 to more than 400) a weighted mean annual concentration was computed as follows:

$$\bar{C} = \frac{\sum_{i=1}^{N} C_i N_i}{\sum_{i=1}^{N} N_i}$$

where: $\bar{C}$ = mean annual concentration for N years
i = year 1,2,3 . . . N
C_i = annual mean concentration for year i
N_i = number of observations used in calculating annual mean concentration for year i.

Except for the Nelson River at Kettle Crossing site, all discharge data used in this report for the calculation of loadings were those provided by the WRB (Environment Canada, 1980; Environment Canada 1980a). The discharge data at the Kettle Crossing site were provided by Manitoba Hydro, Winnipeg, Manitoba. In the majority of cases, the discharge site and the water quality site are for all intents and purposes co-located. The exceptions were Churchill River below Wasawakasik (5), Saskatchewan River above Carrot River (19), Souris River near Coulter (21) and Winnipeg River at Point Du Bois (23). For the purposes of this report, flows were not corrected for consistency with the water quality site.

RESULTS AND DISCUSSION

The TP, TN and TOC data collected at the Manitoba interjurisdictional sites between 1970 and 1979 are summarized in Table 3. It is apparent from this table that the number of samples varied substantially among the rivers, ranging from 13 samples for the Hayes River to 1,656 samples for the Red River over the ten years. To a lesser extent, the number of samples varied among parameters. In the cases of the rivers with very few samples it is apparent that the requirement to have at least 3 samples per year to include a year of data has significantly reduced the data base for these sites. This requirement is still considered valid because of the general assumption that the available data must be capable of characterizing annual conditions.

The mean annual concentrations of the macro-nutrients varied greatly among the sites. The general tendency is for lowest nutrient concentrations to occur at the northern sites and the highest to occur in the south. A similar pattern is noted for the broad range of annual mean concentrations for each site. This variability and the overall complexity of the data base reflects the variable nutrient quality of the widely differing sites as well as the inconsistencies in sampling frequencies and the limited ability of these data to characterize nutrient quality. Consequently, a series of data summaries are presented below in an effort to further interpret the results. Specifically, the gross spatial patterns which provide a general overview of nutrient chemistry will be presented, first using both the aggregated mean annual data and the annual mean nutrient quality data. As the data permit for specific sites, the seasonal nutrient fluctuations will be assessed in the context of the controlling physical, biological and chemical processes. Finally, the limited data base available for species will be summarized in light of the preceding information.

Table 3: Summary of TP, TN, and TOC Data Collected for the Manitoba Interjurisdictional Sites (1970 - 79)

Map Location	Sampling Sites	# of Samples	TP(mg/L) Mean Annual Con.	Range of Annual Mean	# of Samples	TN(mg/L) Mean Annual Con.	Range of Annual Mean	# of Samples	TOC(mg/L) Mean Annual Con.	Range of Annual Mean
1	Antler River at Hwy 251	66	.164	0.142-0.215	53	1.62	1.10-1.86	69	18.4	10.9-19.6
2	Assiniboine River below Kamsack	76	.163	0.090-0.528	78	1.70	1.12-2.49	87	17.1	12.7-24.6
3	Badger Creek at Carturight	53	.123	0.083-0.159	51	1.48	1.07-1.98	55	16.0	11.2-22.5
4	Churchill River above Red Head Rapids (RHR)	16	.020	0.012-0.023	14	0.68	0.45-1.19	21	9.5	7.7-12.0
5	Churchill River below Wasawakasik (W)	49	.017	0.012-0.030	50	0.38	0.27-0.77	52	7.4	5.8-10.0
6	Cochrane River near Brochet	26	.018	0.006-0.042	18	0.38	0.13-0.55	30	5.7	4.8- 6.6
7	Gainsborough Creek at Hwy 83	56	.195	0.156-0.269	42	1.69	1.20-2.12	59	17.3	10.9-19.0
8	Hayes River Below God's River	13	.012	0.008-0.015	13	0.62	0.62-0.64	19	11.2	10.3-12.6
9	Manigotagan River at Hwy 304	91	.034	0.022-0.075	85	0.84	0.50-1.18	92	15.9	13.7-17.3
10	Nelson River at Kettle Crossing	26	.020	0.009-0.033	36	0.77	0.58-1.19	45	9.4	8.0-11.2
11	Overflowing River at Hwy 10	32	.027	0.012-0.052	29	1.06	0.89-1.38	32	26.0	22.8-28.8
12	Pembina River near Windygates	64	.215	0.174-0.326	63	1.29	0.74-1.93	71	12.3	9.4-18.3
13	Pine Creek Diversion at Hwy 89	69	.028	0.011-0.044	70	0.56	0.46-0.78	77	10.1	7.6-12.3
14	Pipestone Creek at Hwy 255	17	.176	0.102-0.257	17	1.84	1.18-2.82	16	15.9	12.4-19.7
15	Qu'Appelle River south of Welby	91	.258	0.213-0.376	100	1.29	1.07-1.52	109	14.1	8.2-22.2
16	Red River at Emerson	1656	.220	0.175-0.451	1622	1.33	1.19-1.88	113	15.0	12.2-18.9
17	Red Deer River at Erwood	71	.082	0.036-0.209	71	1.18	0.98-1.36	92	19.7	14.6-29.5
18	Roseau River at Gardenton	83	.063	0.047-0.090	83	1.16	0.81-1.44	97	20.8	16.1-24.6
19	Saskatchewan River above Carrot River	120	.060	0.038-0.106	126	0.79	0.55-1.12	126	9.2	6.0-14.2
20	Seal River below Great Island	20	.007	0.005-0.009	17	0.59	0.36-0.80	23	8.3	6.3-11.3
21	Souris River near Coulter	521	.281	0.231-0.538	490	1.85	1.75-2.99	212	21.0	16.0-24.4
22	Swan River at Hwy 10	30	.100	0.038-0.247	26	1.08	0.88-1.53	28	15.4	14.1-17.8
23	Winnipeg River at Point DuBois	35	.020	0.019-0.023	35	0.46	0.39-0.65	38	9.3	8.5-11.0
24	Woody River at Hwy 10	32	.039	0.024-0.065	29	0.92	0.73-1.26	32	15.5	13.5-20.3

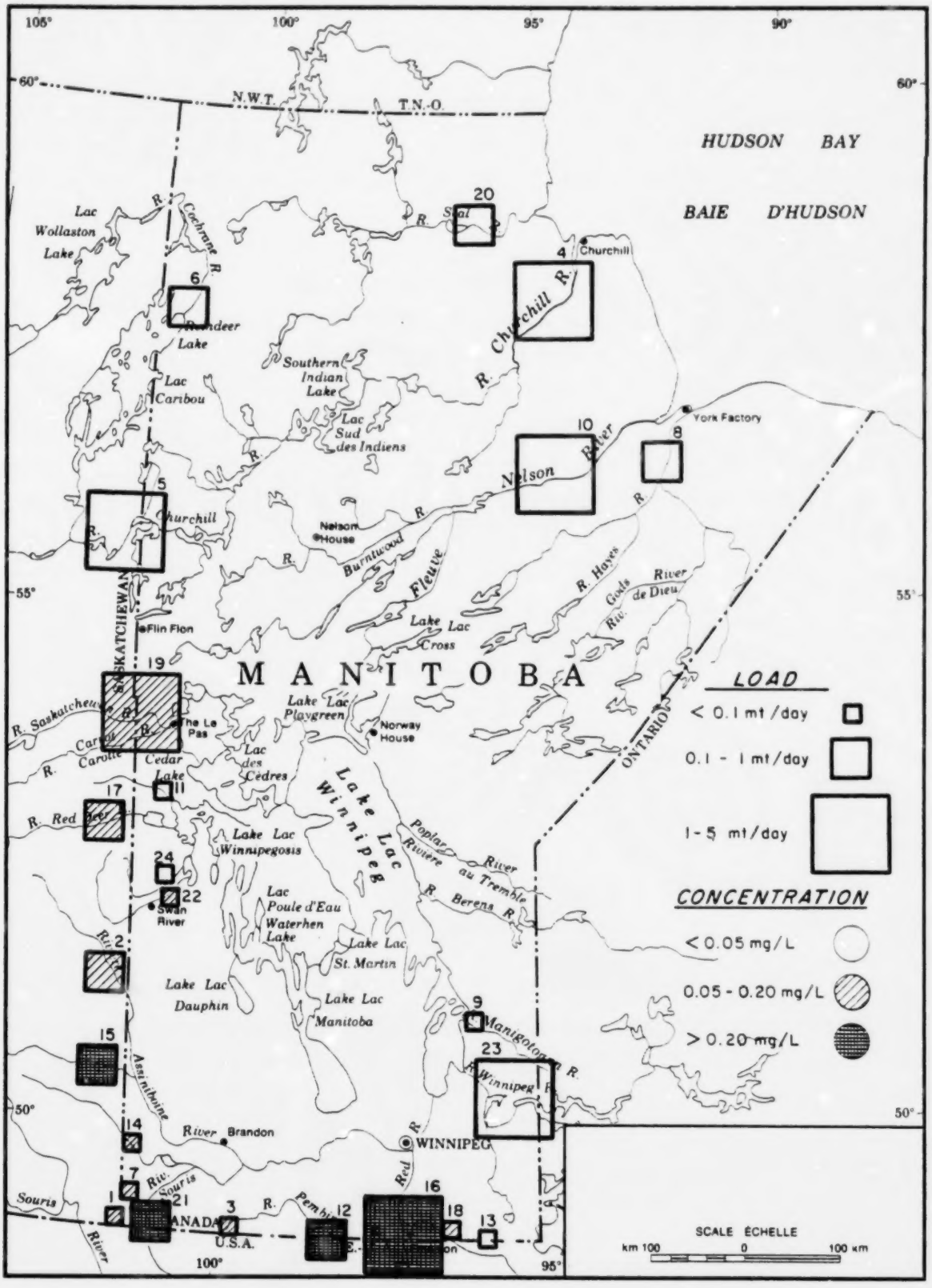
(i) Spatial Pattern

The province of Manitoba can be divided according to bedrock geology which in turn reflects drainage basin characteristics, soil and overburden material, vegetation or land use, as well as anthropogenic influences such as municipal and industrial discharges. Accordingly, the water quality sites have been sorted and ranked within the Palaeozoic-Mesozoic Region and the Pre-Cambrian Region of the province in Table 4. The majority of the rivers occur in the Palaeozoic-Mesozoic Region which generally consists of highly productive agricultural lands (see Figures 2 and 3). It is apparent from Table 4 that most of these rivers are characterized by higher nutrient levels than the rivers of the Pre-Cambrian Region. Exceptions to this general pattern are readily apparent and are indicative of the complex interaction of the processes determining nutrient water quality.

Within the Palaeozoic-Mesozoic Region, mean annual TP concentrations differed by an order of magnitude, from 0.027 mg/L for Overflowing River to 0.281 mg/L for the Souris River. As illustrated in Figure 4, only the Woody and Overflowing Rivers are characterized by TP concentrations more characteristic of the Pre-Cambrian Region rivers. This observation is consistent with the essentially natural wooded drainage basin of these two river systems in contrast to the agricultural and mixed land-use characteristics of the other southern and southwestern basins. The differences in TP concentrations between forested and agricultural watersheds has been documented in other studies including U.S. Environmental Protection Agency (1977) and the International Joint Commission's Pollution from Land Use Activities Reference Group (1978). All of the rivers in the Pre-Cambrian Region can be considered to have naturally low TP concentrations ranging from 0.007 mg/L to 0.034 mg/L for the Seal and Manigotagan Rivers, respectively.

The range in TN concentrations for the rivers of the two regions is somewhat reduced relative to TP. In the Palaeozoic-Mesozoic Region the range is 0.79 mg/L to 1.85 mg/L for the Saskatchewan and Souris Rivers

Figure 4. Mean Annual TP Concentration and Mean Annual TP Load (1970-79)



respectively, with only the Woody and Saskatchewan Rivers having a mean annual TN concentration of less than 1 mg/L. In contrast, all of the rivers of the Pre-Cambrian Region (Figure 5) have TN concentrations less than 1 mg/L and range between 0.4 and 0.8 mg/L.

The general nutrient quality pattern for the province of Manitoba is maintained by the TOC summary data. The Palaeozoic-Mesozoic Region rivers generally have higher TOC concentrations ranging from 9.2 mg/L to 26.0 mg/L for the Saskatchewan and Overflowing Rivers, respectively. As shown in Figure 6, however, there is more overlap in the range of TOC concentrations between the two regions, with three of the Pre-Cambrian sites having TOC concentrations greater than 10.0 mg/L. It is apparent that the forests, swamps and bogs characterizing the rivers of the Pre-Cambrian Region and some of the more southerly rivers, can contribute as much, and frequently more, allocthonous organic matter to rivers as do agricultural lands. Most noteable is the Overflowing River, which although it had the lowest TP concentration for the Palaeozoic-Mesozoic Region, has the highest TOC concentration of all sites (26.0 mg/L).

The wide range of annual mean concentrations for each site is seen in Table 3. This variation is illustrated for each river in Figures 7 and 8. The annual mean discharge for each site is also shown. Most noteworthy in Figures 7 and 8 are the data gaps which occur at individual sites due to years with no data or inadequate data (i.e. fewer than 3 samples per year). This severely limits a general assessment of annual variability of nutrient quality at many sites, and precludes it for Antler Creek, Churchill River (R.H.R.), Cochrane River, Gainsborough Creek, Hayes river, Nelson River, Overflowing River, Pipestone Creek, Swan River and Woody River.

Contrasting the remaining five Pre-Cambrian Region sites (i.e.Churchill River (W), Manigotagan River, Pine Creek, Seal River and Winnipeg River) with the sites of the Palaeozoic-Mesozoic Region, it is apparent that both annual mean flows and nutrient concentrations vary considerably less in the former group. A natural variability due to climatic differences

Table 4: Ranking of TP, TN and TOC Mean Annual Concentrations for Manitoba Interjurisdictional Sites (1970-79)

(Palaeozoic-Mesozoic Region)

River	TP (mg/L)	River	TN (mg/L)	River	TOC (mg/L)
Souris R	0.281	Souris R	1.85	Overflowing R	26.0
Qu'Appelle R	0.258	Pipestone Cr	1.84	Souris R	21.0
Red R	0.220	Assiniboine R	1.70	Roseau R	20.8
Pembina R	0.215	Gainsborough Cr	1.69	Red Deer R	19.7
Gainsborough Cr	0.195	Antler R	1.62	Antler R	18.4
Pipestone Cr	0.176	Badger Cr	1.48	Gainsborough Cr	17.3
Antler R	0.164	Red R	1.33	Assiniboine R	17.1
Assiniboine R	0.163	Qu'Appelle R	1.29	Badger Cr	16.0
Badger Cr	0.123	Pembina R	1.29	Pipestone Cr	15.9
Swan R	0.100	Red Deer R	1.18	Woody R	15.5
Red Deer R	0.082	Roseau R	1.16	Swan R	15.4
Roseau R	0.063	Swan R	1.08	Red R	15.0
Saskatchewan R	0.060	Overflowing R	1.06	Qu'Appelle R	14.1
Woody R	0.039	Woody R	0.92	Pembina R	12.3
Overflowing R	0.027	Saskatchewan R	0.79	Saskatchewan R	9.2
Median	0.163		1.29		16.0

(Precambrian Shield)

Manigotagan R	0.034	Manigotagan R	0.84	Manigotagan R	15.9
Pine Cr	0.028	Nelson R	0.77	Hayes R	11.2
Churchill R (RHR)	0.020	Churchill R (RHR)	0.68	Pine Cr	10.1
Nelson R	0.020	Hayes R	0.62	Churchill R (RHR)	9.5
Winnipeg R	0.020	Seal R	0.59	Nelson R	9.4
Cochrane R	0.018	Pine Cr	0.56	Winnipeg R	9.3
Churchill R (W)	0.017	Winnipeg R	0.46	Seal R	8.3
Hayes R	0.012	Churchill R (W)	0.38	Churchill R (W)	7.4
Seal R	0.007	Cochrane R	0.38	Cochrane R	5.7
Median	0.020		0.59		9.4

Figure 5. Mean Annual TN Concentration and Mean Annual TN Load (1970-79)

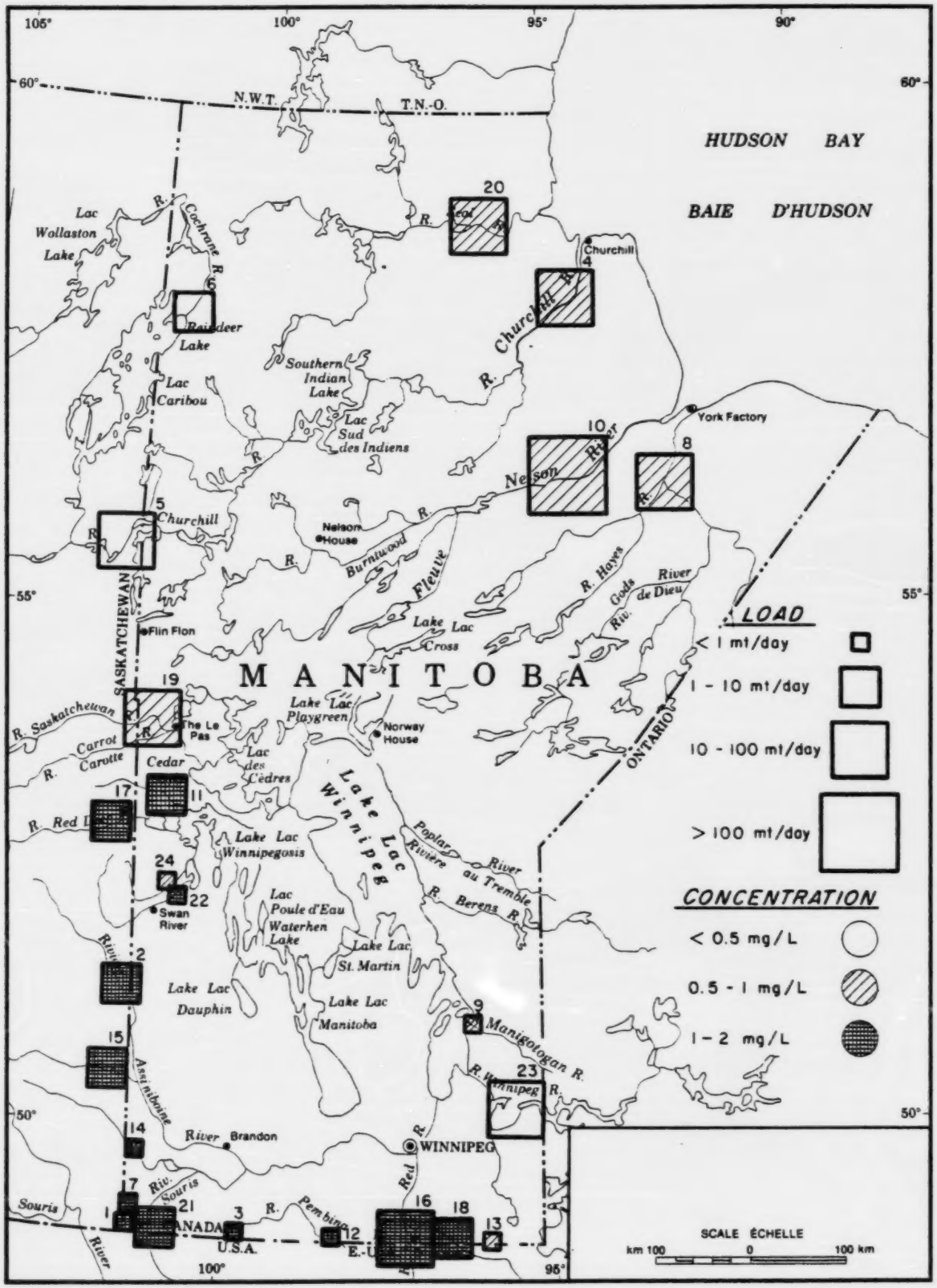
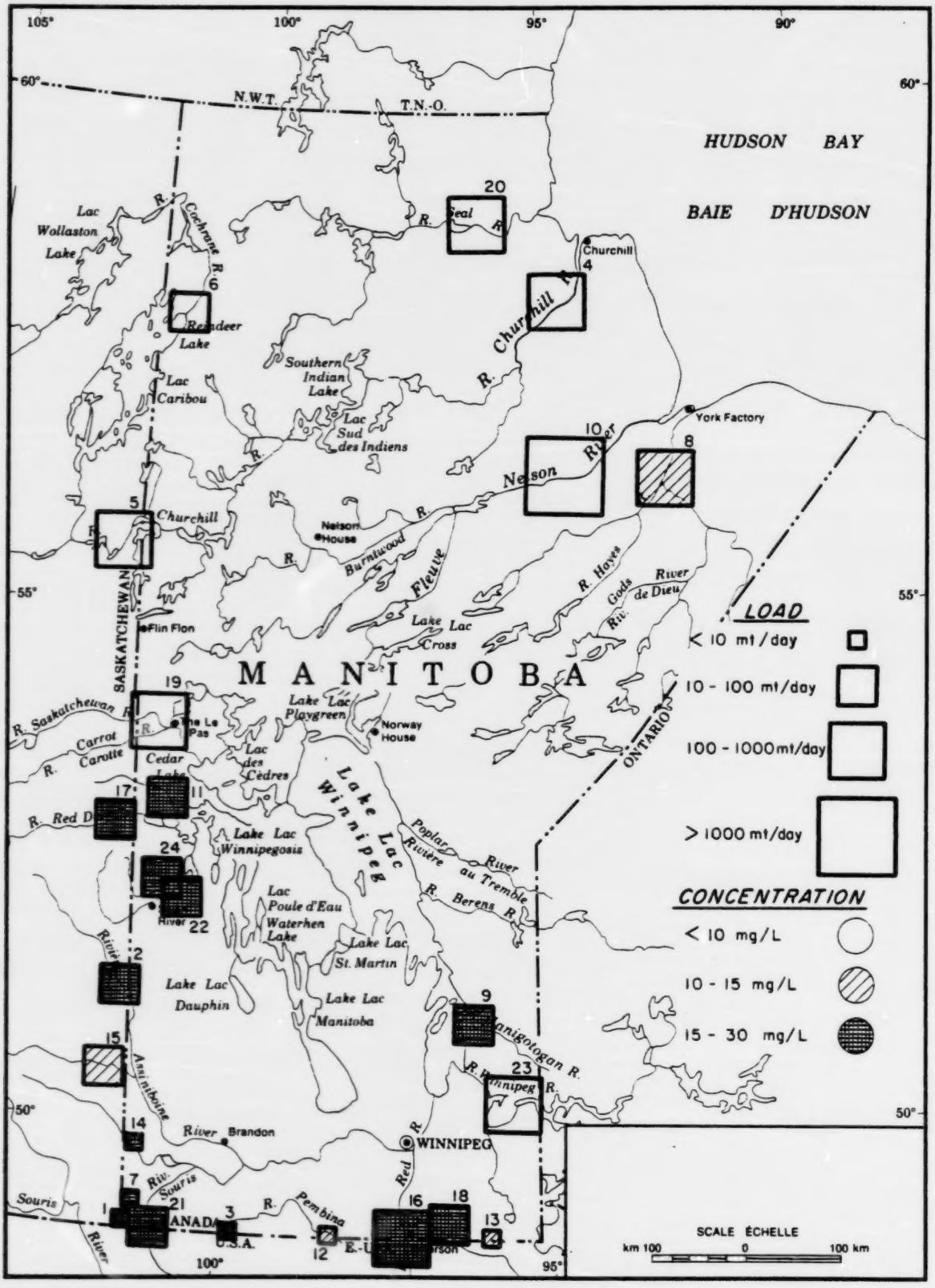


Figure 6. Mean Annual TOC Concentration and Mean Annual TOC Load (1970-79)



is to be expected in river systems. The accentuation of this difference in the Palaeozoic-Mesozoic Regions is probably primarily a function of the decreased total annual precipitation from east to southwest and the reduced natural storage of the generally smaller southern watersheds. Consequently, many of the southern rivers are susceptible to very low flows. The driest years during the 1970's in Manitoba were 1973, 1977 and 1978 (see Figures 7 and 8).

Interestingly, the nutrient concentration response to these low flows was not consistent among the rivers. For example, in the Assiniboine River, Badger Creek and Qu'Appelle River, TN and TP concentrations decreased in the dry years of 1977 and 1978, whereas an increase in TN and TP is observed for the same two years for the Red and Souris rivers and Pipestone Creek.

In a semi-arid environment, it is important to have an understanding of the effects of year to year flow variations on nutrient concentrations. For example, the quality of water in many Prairie rivers and lakes is generally poorest during low flow years. However, these data are too limited to present a generalized pattern for the province and detailed discussion of each basin is beyond the scope of this report. This phenomenon is the subject of a report on a more detailed nutrient study of the Souris River basin, conducted during 1979 and 1980 (Chacko, 1986).

Water quality objectives are commonly used as the basis upon which to assess stream quality and determine the need for water quality improvements. A widely accepted concentration objective for TP for water flowing to lakes and reservoirs is 0.05 mg/L (USEPA, 1977). If this objective is accepted, it is readily apparent from Table 4 that all rivers of the Palaeozoic-Mesozoic Region, except for the Woody and Overflowing Rivers, would be non-compliant. The Prairie Provinces Water Board (PPWB, 1983) has suggested a TN objective of 1.0 mg/L for rivers of the plains. All the sites in the Palaeozoic-Mesozoic Region, except for the Woody and Saskatchewan rivers, exceed the PPWB objective for TN. It is difficult to set an objective for TOC because it encompasses a variety of complex organic compounds.

Figure 7. Annual Mean TP, TN and TOC Concentrations and Discharge for Rivers of the Precambrian Region (1970-1979).

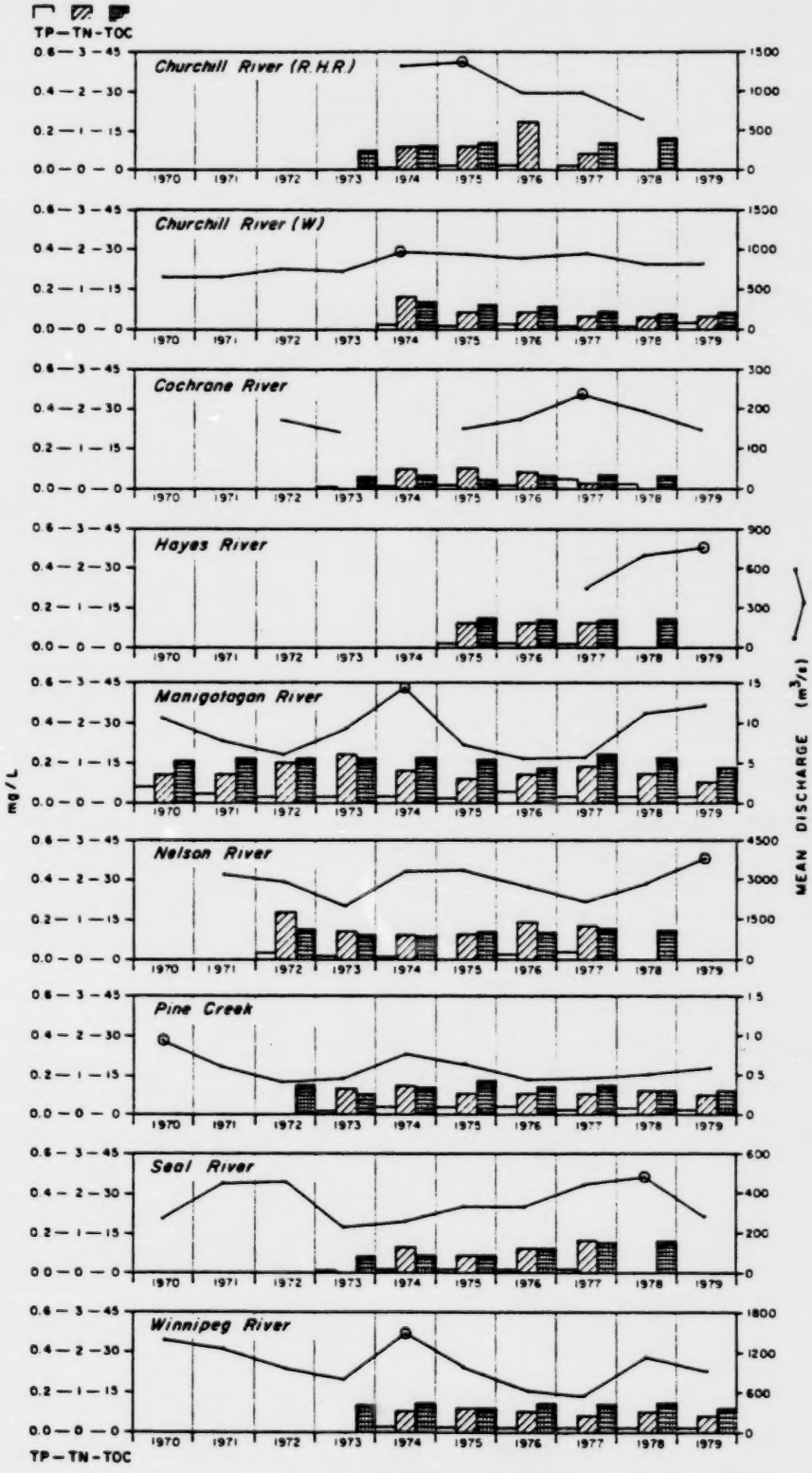


Figure 8. Annual Mean TP, TN and TOC Concentrations and Discharge for Rivers of the Palaeozoic-Mesozoic Region (1970-1979).

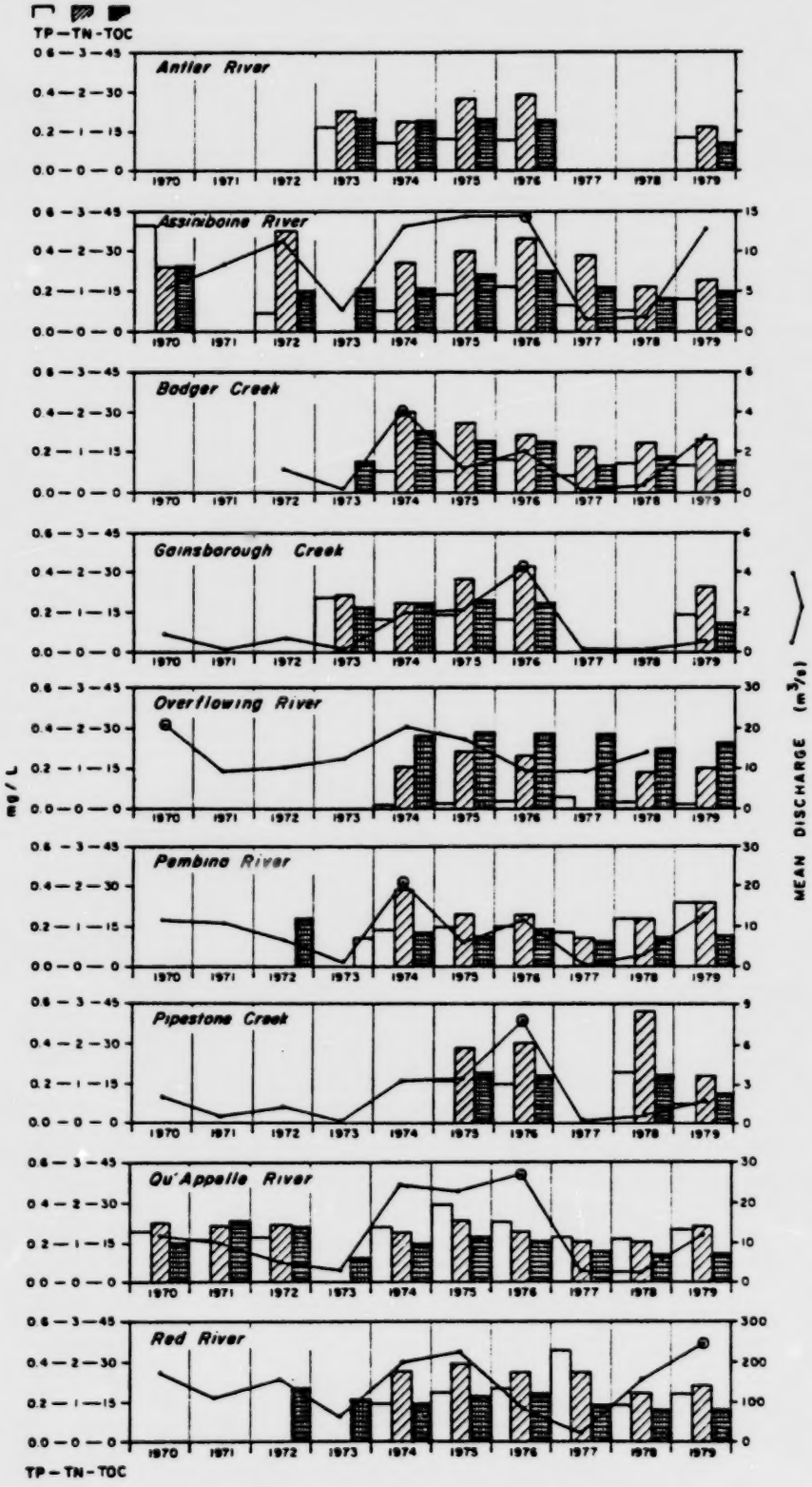
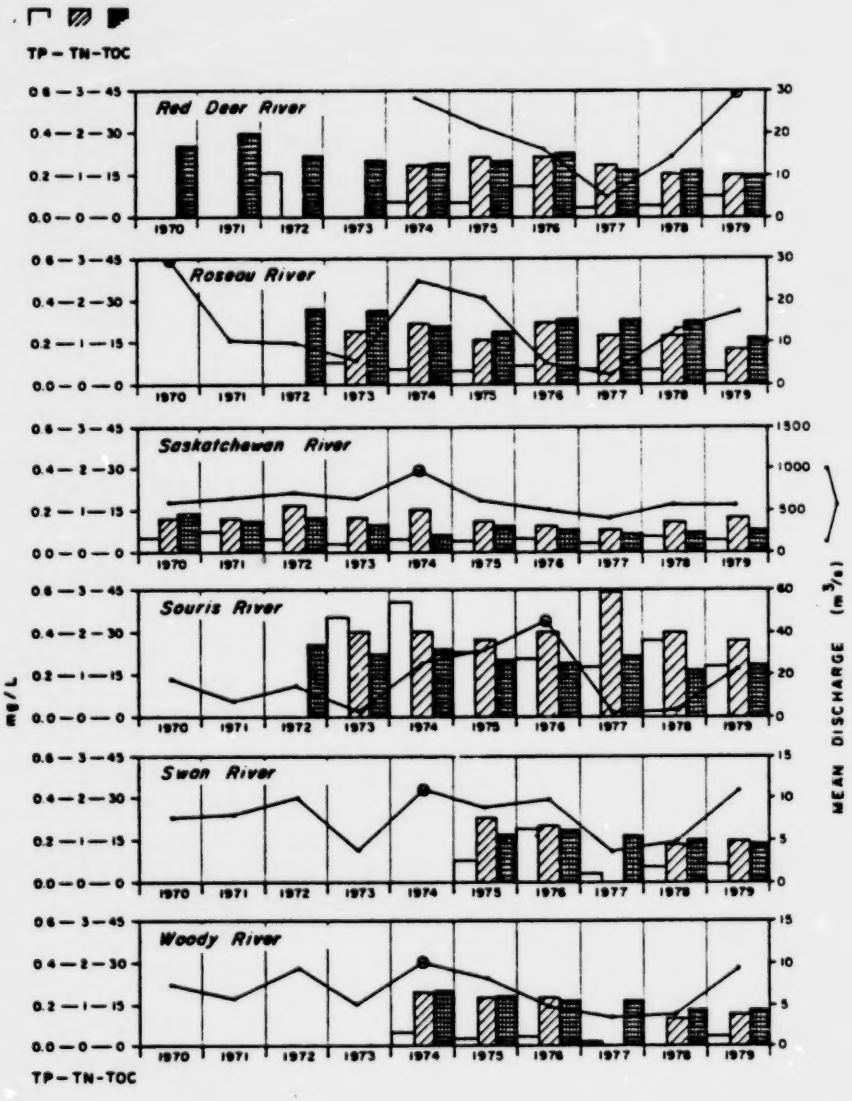


Figure 8 (continued)



In the context of eutrophication, it is frequently the loadings of nutrients to a downstream lake or reservoir which are of greater concern than simply nutrient concentrations. The loadings in this report were calculated as "mean annual loads" as follows:

$$L_a = \left(\sum_{i=1}^{n} C_a Q_a k \right) / n$$

where : L_a = mean annual load (tonnes/day);

$\overline{C_a}$ = annual mean concentration for year i;

$\overline{Q_a}$ = annual mean flow for year i;

i = 1, 2, 3 . . . n years; and,

k = a constant to provide appropriate units.

n = number of years

This is a very simplified method of load calculations and the authors caution that these loads, although indicative of relative differences among river systems, should be assumed to only approximate absolute loadings. Trends in loadings during the period of record have been assumed to be negligible.

The nutrient loadings for the 24 interjurisdictional river sites are summarized in Table 5 as well as Figures 4, 5, and 6. It is readily apparent in the table or the figures, that the river loadings no longer maintain their regional characterization. This is a direct result of the consideration of flow in the loading equation which can yield a high load even with very low concentrations. As a result, the very large river systems of the northern part of the province tend to dominate. For example, the Saskatchewan River, although having relatively low nutrient concentrations for rivers in the Palaeozoic- Mesozoic Region, accounts for about 30% of each of the TP and TN loads into the province and 20% of the TOC loading. The largest inflowing

Table 5: Mean Annual Discharge and Estimated Nutrient Load Entering Manitoba at the Interjurisdictional Sites Based on 1970-79 Data

River	Map Location	Mean Annual Discharge (m^3/s)	TP mt/yr	TP %	TN mt/yr	TN %	TOC mt/yr	TOC %
Winnipeg R	23	1042	626	15.4	15611	26.7	291,120	33.5
Churchill R (W)	5	854	485	11.9	12169	20.8	223,969	25.8
Saskatchewan R	19	630	1231	30.2	16203	27.7	183,861	21.2
Cochrane R	6	180	124	3.0	1888	3.2	34,441	4.0
Red R	16	140	1067	26.2	7460	12.8	66,225	7.6
Red Deer R	17	19	49	1.2	710	1.2	10,961	1.3
Souris R	21	18	202	5.0	1158	2.0	12,420	1.4
Roseau R	18	13	22	0.5	437	0.7	7,352	0.8
Overflowing R	11	13	11	0.3	527	0.9	11,657	1.3
Qu'Appelle R	15	12	116	2.8	536	0.9	5,680	0.7
Manigotagan R	9	8.9	10	0.2	214	0.4	4,464	0.5
Assiniboine R	2	8.5	52	1.3	559	1.0	4,851	0.6
Swan R	22	8.0	30	0.7	330	0.6	3,842	0.4
Woody R	24	7.2	10	0.2	249	0.4	3,690	0.4
Pipestone Cr	14	2.1	20	0.5	198	0.3	1,832	0.2
Badger Cr	3	1.5	7	0.2	92	0.2	883	0.1
Gainsborough Cr	7	1.1	9	0.2	99	0.2	981	0.1
TOTAL			4071		58440		868,229	

Discharge values for Overflowing, Woody and Gainsborough were based on measurements taken from March to October, hence these values are some what higher than the actual mean annual values.

river, the Winnipeg, accounts for 15, 27 and 34% of the average loadings of TP, TN and TOC, respectively.

As noted by Brunskill (1974), the southern portion of Lake Winnipeg is approaching an eutrophic state. Thus, the loadings of the five rivers to the southern part to Lake Winnipeg are important, although these loadings may be relatively small in the province-wide context. These rivers are the Winnipeg, Red, Souris, Qu'Appelle and Assiniboine. The Winnipeg river has the highest TOC load, the second highest TN load and the third highest TP load in the province (291,120, 15,611 and 626 mt/yr for TOC, TN and TP respectively). The Red River accounts for additional loadings of 7460, 66,225 and 1067 tonnes/year of TN, TOC and TP respectively. The loads reported here for the other three systems are considerably smaller. These loads for all but the Winnipeg River can be misleading due to the fact that the water quality stations are a considerable distance upstream and do not include large tracts of agricultural land and the major urban centres of Manitoba. Further evaluation of nutrient loadings to southern Lake Winnipeg would require amalgamation of these data with provincial data.

(ii) Annual Cycles

Rivers generally show an annual cycle of nutrient concentration. This cycle can vary greatly among basins depending upon the natural and anthropogenic characteristics of the watershed. In addition, the availability of the nutrient data can significantly affect the appearance of an annual nutrient cycle. This is especially noticeable in the rivers of Manitoba which are not sampled monthly. For this section, the basic distinction between Pre-Cambrian and Palaeozoic-Mesozoic Region rivers will again be used.

The mean TP, TN and TOC concentrations aggregated for each month for which data are available for the period 1970-1979 (i.e., mean monthly) are shown in Figures 9 and 10 for the rivers of the Pre-Cambrian Region and Palaeozoic-Mesozoic Region respectively. It is quite evident from

Figure 9 that the distribution of samples is severely limited to a few months of the year. This is especially evident for the Churchill River (RHR), Cochrane River, Hayes River and Seal River. The number of samples for each month for the remaining rivers is very limited. This is a direct result of the sampling program designed for these remote sites which consists of only approximately quarterly visits each year. The exceptions are the Churchill River (W), the Manigotagan River, Pine Creek, and Winnipeg River. These sites frequently lack data for the spring or fall due to unsafe ice conditions for sampling, or because they dry up in the winter time, as in the case of Pine Creek. The basins of the Palaeozoic-Mesozoic Region are generally sampled on a monthly basis except for Badger Creek, Gainsborough Creek, Overflowing River, Pipestone Creek, Swan River and Woody River which show data gaps during the winter, and in some cases, the summer as well. This is a direct result of no flow in these systems at these times during most years. Despite these data limitations, it is assumed below that the annual cycles in each system are fully characterized by the data presented in Figures 9 and 10.

The very low concentrations and the general lack of variability in TP, TN and TOC concentrations characterize all of the Pre-Cambrian Region rivers. In the rivers with adequate data, specifically the Churchill River (W), Manigotagan River, and Pine Creek, it is also evident that the approximate ratios of each of the three nutrients remains fairly constant throughout the year.

Although far from a consistent pattern for all rivers of the Palaezoic-Mesozoic Region, there is a tendency for (i) TP to peak the month before, or the same month as the high flows; (ii) TN to peak during late winter, decline during the spring and summer, and increase again in the fall; and (iii) TOC to be generally uniform throughout the year or to peak in the spring and/or fall. Worthy of further note are: (i) the high TP and TN concentrations observed for the Qu'Appelle River during July and August; (ii) the general lack of monthly variation for all three nutrients in the Saskatchewan River; and (iii) the very high TP and relatively high TOC concentrations in the Souris River during the winter

Figure 9. Mean Monthly TP, TN and TOC Concentrations and Discharge for Precambrian Region Rivers (1970-1979).

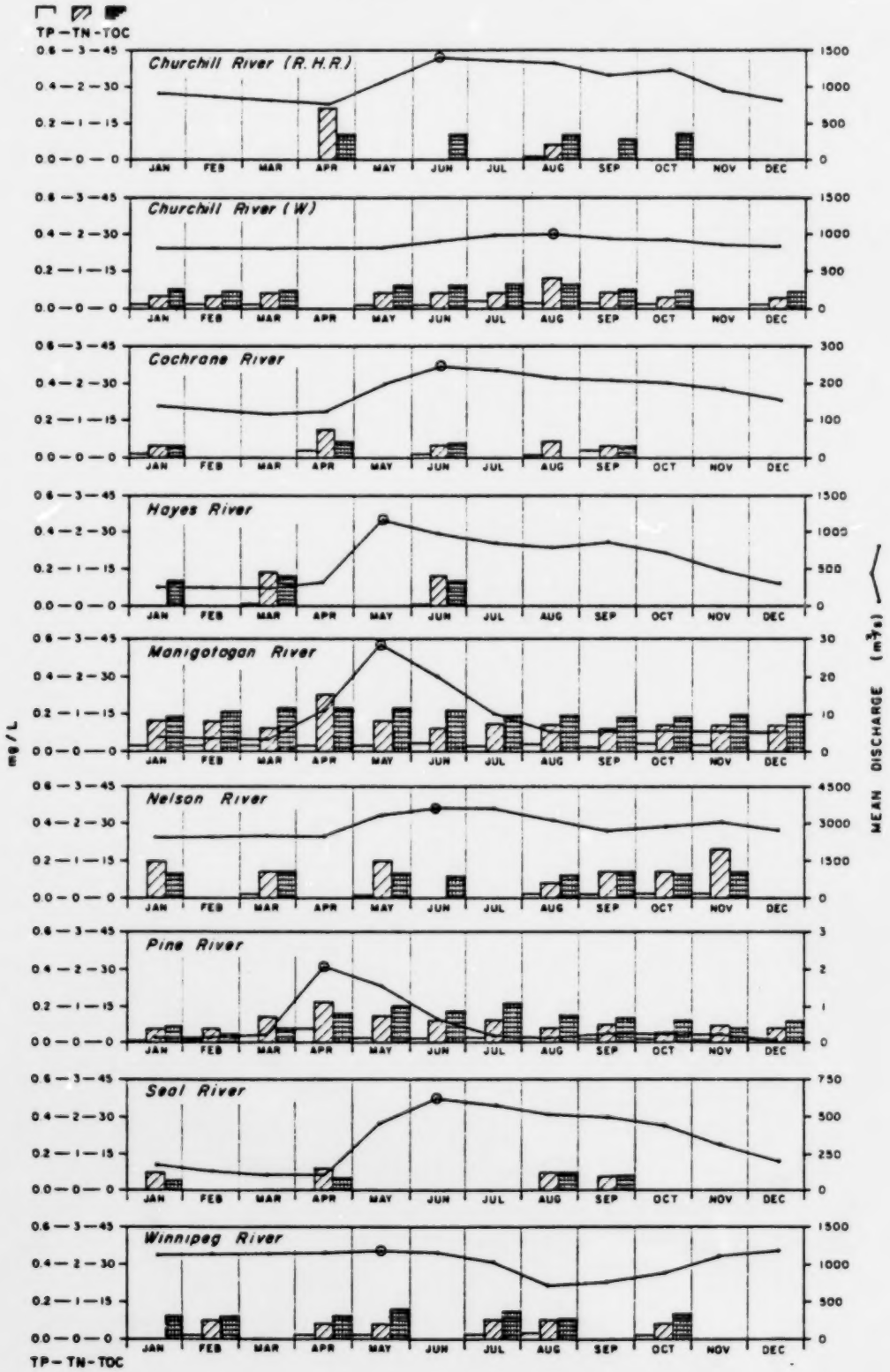


Figure 10. Mean Monthly TP, TN and TOC Concentrations and Discharge for Palaeozoic-Mesozoic Region Rivers (1970-1979).

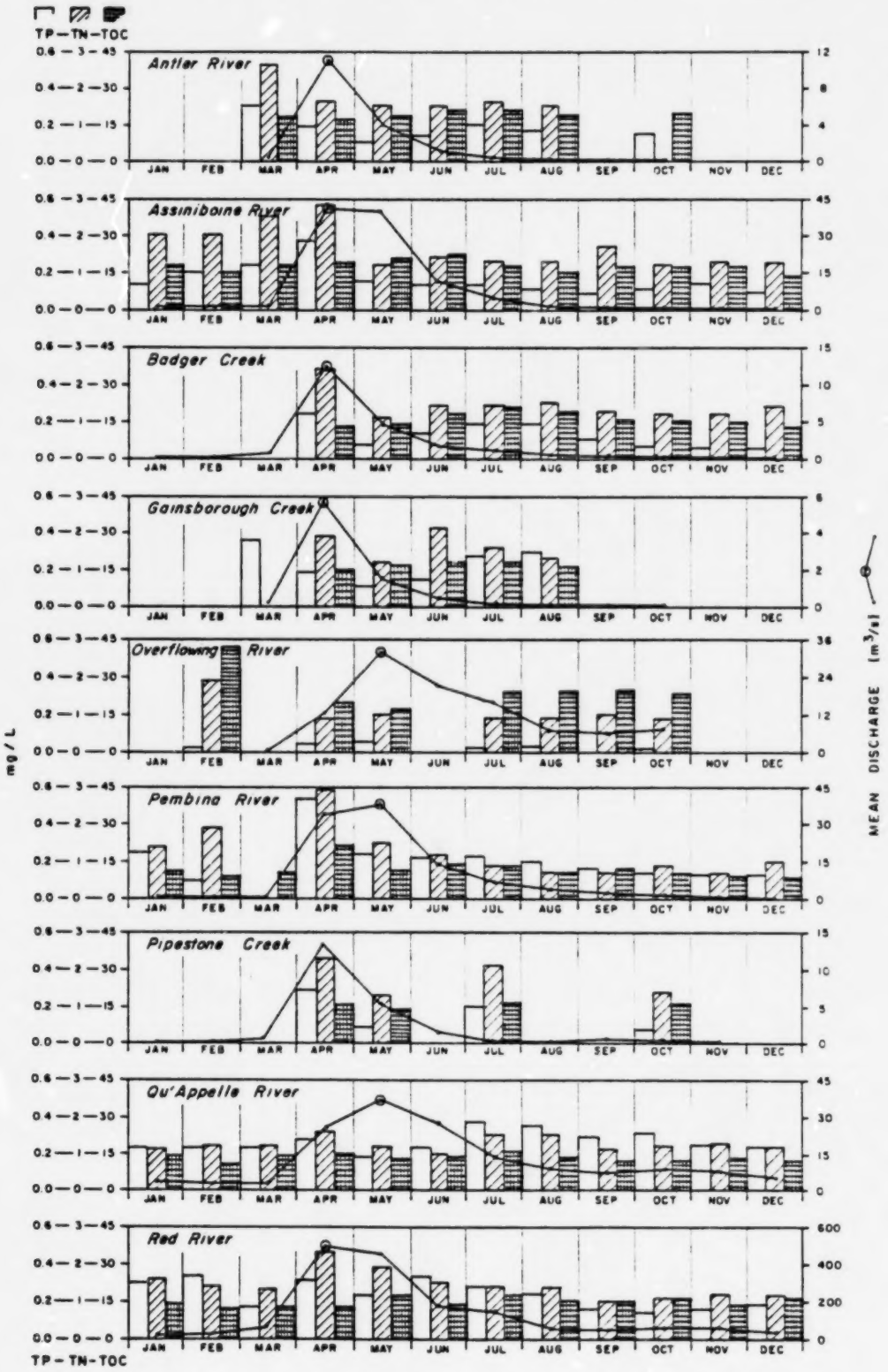
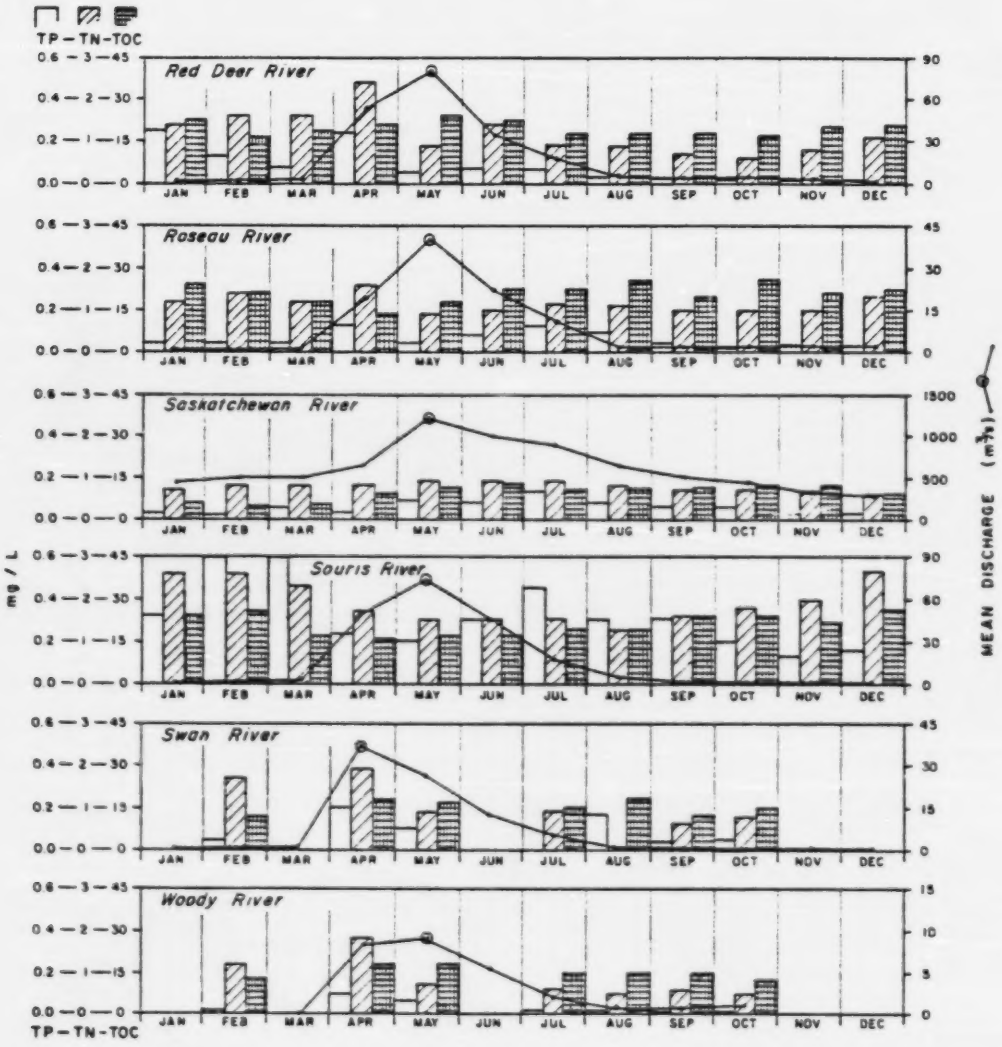


Figure 10 (continued).



low flow period. These observations warrant further discussion.

TP is comprised of both soluble and particulate forms (see below) and in a fluvial system the ratio between these two forms is generally determined by an interaction of a number of hydrophysical factors. In general, high instream flows in association with overland runoff such as occurs during spring melt or major precipitation events account for the periods of peak particulate phosphorus concentrations and commonly maximum TP concentrations. This phenomenon explains the tendency for TP to peak in association with high spring flows in most of the rivers of the Palaeozoic-Mesozoic Region.

TN, on the other hand, peaks during the winter when groundwater is comprising the major portion, if not all, of the flow. Groundwater is generally characterized by high nitrogen concentrations relative to surface waters (McCarty et al., 1970), and thus the winter maximum is to be expected. The spring minimum is a direct result of the dilution of nitrogen rich baseflow waters by surface melt waters with low TN concentrations. The increasing TN concentrations in the fall reflect the increasing dominance of groundwater, thereby completing the cycle to the winter maximum. This pattern is exemplified by the Red Deer River in Figure 10.

TOC is less variable although there is a tendency for TOC to peak in the spring and/or fall. Generally, allochthonous organic matter accounts for much of the TOC and thus fall peaks as a result of dying and decaying vegetation, including tree leaves and aquatic vegetation, are the norm. Spring peaks will occur in basins where the overland flow during spring melt is capable of transporting organic matter to the watercourse.

There are, however, several systems which by way of their variance from this general cycle warrant further discussion, specifically the Qu'Appelle, Saskatchewan and Souris Rivers. The Qu'Appelle basin (Figure 10) has high TN and TP concentrations throughout the year, but the

maximums occur in the late summer as opposed to the spring. A number of lakes occur in the Qu'Appelle system upstream of the Saskatchewan-Manitoba border, and although TP input concentrations to these lakes peak in the spring (Munro, 1984) the lakes permit considerable sedimentation. Additionally, the residence time of the lakes, and the biological, chemical and physical processes affecting nutrients within the lakes, have an obvious effect on the timing and type of phosphorus released downstream (Munro, 1984). The reason for summer maximum TN concentrations can not be explained at this time due to the fact that TN export concentrations from the Fishing Lakes are generally a minimum during the summer months.

The Saskatchewan River shows much less monthly variability than the other rivers and in this regard is more comparable to the rivers of the Pre-Cambrian Region. TP does peak in the summer as do TN and TOC, but all are without the pattern noted above. A complete review of the Saskatchewan River system would be required to better define and explain this pattern. It is expected, however, that the very complex nature and size of the Saskatchewan basin (e.g., many tributaries including glacial meltwaters and prairie streams, reservoirs, lakes, and urban inputs) interact in a manner which tends to smooth the extreme concentrations.

The Souris basin, with respect to TP, peaks during February and March. Two causes are postulated. First, the massive, shallow, nutrient rich marshes in North Dakota may release phosphorus under ice cover. This has been observed to occur when surface waters become anoxic, allowing biochemical release of phosphorus from the marsh sediments (Syers et al., 1973). Second, spring flows can occur quite early in this basin from time to time, thereby simply making the occurrence of high TP somewhat earlier than other rivers. This phenomenon varies from year to year, and thus the most likely explanation for the timing of the maximum TP concentrations is some combination of these two factors. Ongoing work in the Souris basin may provide more information in this regard (Chacko, 1986). No explanation is apparent for the high TP concentrations during July unless it is the result of low flow.

In contrast to other rivers, the Souris shows relatively high TOC concentrations during December, January and February. This occurs after the formation of ice on the system, and therefore it has to be assumed that this organic matter is autochthonous (i.e. internally produced as opposed to externally derived). The most likely source is thought to be the upstream marshes.

(iii) Species Partitioning

An estimate of the biological availability of nutrients is important. Although these data do not indicate bioavailability, samples collected since April, 1978, were analysed for various species of nutrients on the premise that the dissolved nutrient fraction is readily available for biological uptake. These data are summarized for all rivers with more than three samples in Table 6. Due to the limited data available for Antler River, Gainsborough Creek, Churchill River (RHR), and Cochrane River, these systems will be excluded from further discussion.

(a) Phosphorus Species

In general, rivers of the Palaeozoic-Mesozoic Region have a higher portion of phosphorus in the dissolved form. However, the range of 28% to 71% as total dissolved phosphorus for the Swan River and Badger Creek, respectively, shows that there is a great deal of variability. A complete understanding of this variability would require considerably more system specific information than intended in this report. For example, one of the other systems with a high proportion of TDP, following the Badger Creek, is Souris River at 70%. The TP concentrations for the Badger Creek and Souris River for 1978-79 are 0.134 mg/L and 0.286 mg/L, respectively. By inspection of Table 6, it appears that the rivers with the highest concentrations of TP have the greatest proportion of TDP. Rivers such as the Overflowing, Red Deer, Roseau, Saskatchewan, Swan and Woody with TP less than 0.1 mg/L generally have the largest proportion of phosphorus in the particulate form. The exception, in this case, is the Roseau River.

The rivers of the Pre-Cambrian Region range from essentially an even partitioning between the soluble and particulate forms to a dominance of the particulate form. The range is 46% to 78% as PP for the Manigotogan River and Churchill River (W) sites, respectively.

The partitioning of the monthly TP samples for the 1978 to 1979 period are shown in Figure 11. In most river systems, the PP species dominates during the spring freshette as a result of increased flow in the river and the contribution of particulate matter to the stream from land drainage. Otherwise, the pattern is so highly variable that a detailed discussion of each river system and the annual climatic differences would be required to provide a meaningful summary of these results. The one exception is the Souris River which is dominated by the soluble form of phosphorus throughout the year. This is likely due to the contributions from upstream municipal effluent sources and the unknown effects of the extensive wetlands and wildlife refuges on the system within North Dakota.

(b) Nitrogen Species

The nitrogen species in Table 6 and Figure 12 are presented as total dissolved nitrogen (TDN), particulate nitrogen (PN) and nitrate plus nitrite nitrogen (NO_3 + NO_2). It must be remembered, however, that NO_3 + NO_2 are included as part of the TDN fraction, and emphasis will therefore be directed toward the difference between the particulate and dissolved forms of nitrogen. The NO_3 + NO_2 percentages in Table 6 are expressed as the portion of TN comprised of this species.

It is apparent from Table 6 that the rivers of Manitoba are dominated by TDN rather than PN, with the distribution ranging from 57% TDN for the Saskatchewan River to 91% TDN for both the Roseau and Overflowing Rivers. NO_3 + NO_2 comprises a relatively small portion of TN, ranging from 2 to 29% for the Overflowing and Pembina Rivers, respectively. There is, however, a tendency for the relative proportion of NO_2 + NO_3 to increase as PN increases.

Table: 6 Mean Concentration and Relative Proportion of Phosphorus, Nitrogen and Organic Carbon Species and Suspended Sediments for the Manitoba Interjurisdictional Sites (1978-79)

River	Phosphorus Number of Samples	TP mg/L	TDP %	PP %	Nitrogen Number of Samples	TN mg/L	TDN %	PN %	NO_3-NO_2 %	Organic Carbon Number of Samples	TOC mg/L	DOC %	POC %	Suspended Particulate Matter Number of Samples	mg/L
Palaeozoic-Mesozoic Region															
Antler	5	0.146	70	30	5	1.62	58	42	13	5	11.4	90	10	5	3
Assiniboine	20	0.150	63	37	21	1.23	82	18	14	21	14.5	89	11	21	31
Badger Creek	18	0.134	71	29	17	1.23	89	11	18	17	13.1	95	5	17	4
Gainsborough Creek	5	0.166	62	38	5	1.37	77	23	28	5	11.3	87	13	4	4
Overflowing	17	0.025	40	60	18	0.95	91	9	2	18	24.2	98	2	16	8
Pembina	18	0.285	58	42	18	1.36	69	31	29	18	11.6	69	31	18	150
Pipestone Creek	11	0.159	34	66	11	1.78	65	35	8	10	14.2	83	17	11	16
Qu'Appelle	21	0.246	56	44	20	1.21	69	31	16	20	11.2	80	20	21	66
Red	20	0.252	47	53	21	1.54	61	39	18	21	12.9	74	26	19	109
Red Deer	20	0.085	34	66	21	0.93	78	22	21	21	16.3	92	8	21	13
Roseau	21	0.056	56	44	21	0.87	91	9	7	21	17.2	97	3	20	5
Saskatchewan	21	0.024	47	53	21	0.75	57	43	18	21	7.9	76	24	21	55
Souris	21	0.286	70	30	21	1.62	85	15	6	21	17.1	92	8	20	15
Swan	18	0.082	28	72	17	0.90	79	21	18	17	14.4	75	25	15	48
Woody	17	0.036	32	68	17	0.74	82	18	16	17	14.1	77	23	16	21
Mean		0.142	51	49		1.21	76	24	15		14.1	85	15		37
Precambrian Shield															
Churchill (RHR)	3	0.018	-	-	3	0.37	82	18	35	3	11.6	95	5	3	5
Churchill (W)	14	0.024	22	78	14	0.32	78	22	7	14	6.2	94	6	14	2
Cochrane	4	0.009	38	62	4	0.26	74	26	14	4	3.9	90	10	4	1
Manigotagan	20	0.030	54	46	20	0.56	89	11	10	20	1.5	97	3	12	4
Pine Creek	18	0.029	38	62	19	0.54	77	23	11	19	9.1	95	5	19	11
Winnipeg	21	0.019	53	47	21	0.43	85	15	15	21	9.1	96	4	20	4
Mean		0.022	41	59		0.41	81	19	15		9.2	95	5		5

Figure 11. Monthly Phosphorus Species Partitionings for Selected Rivers, 1978 and 1979.

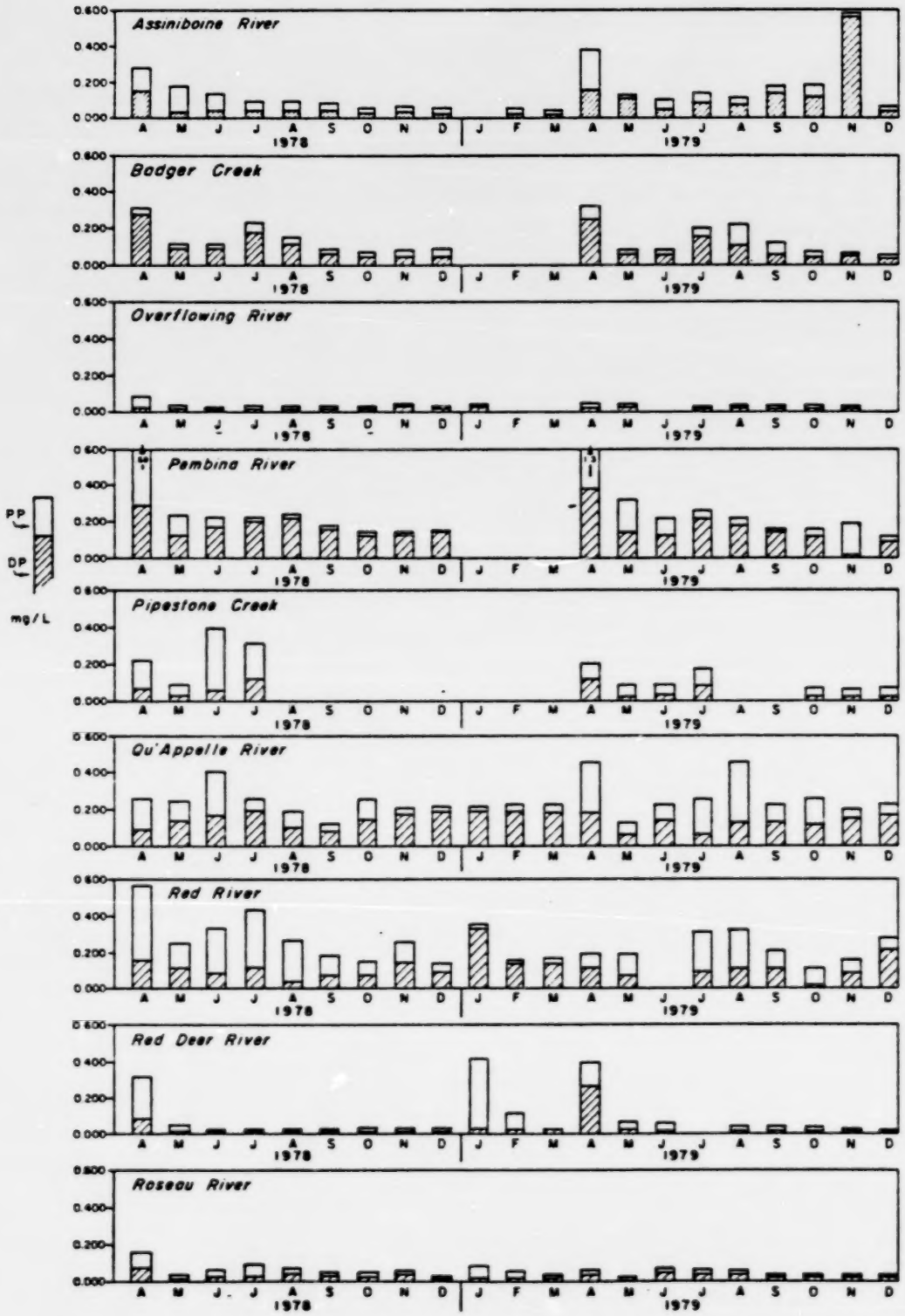
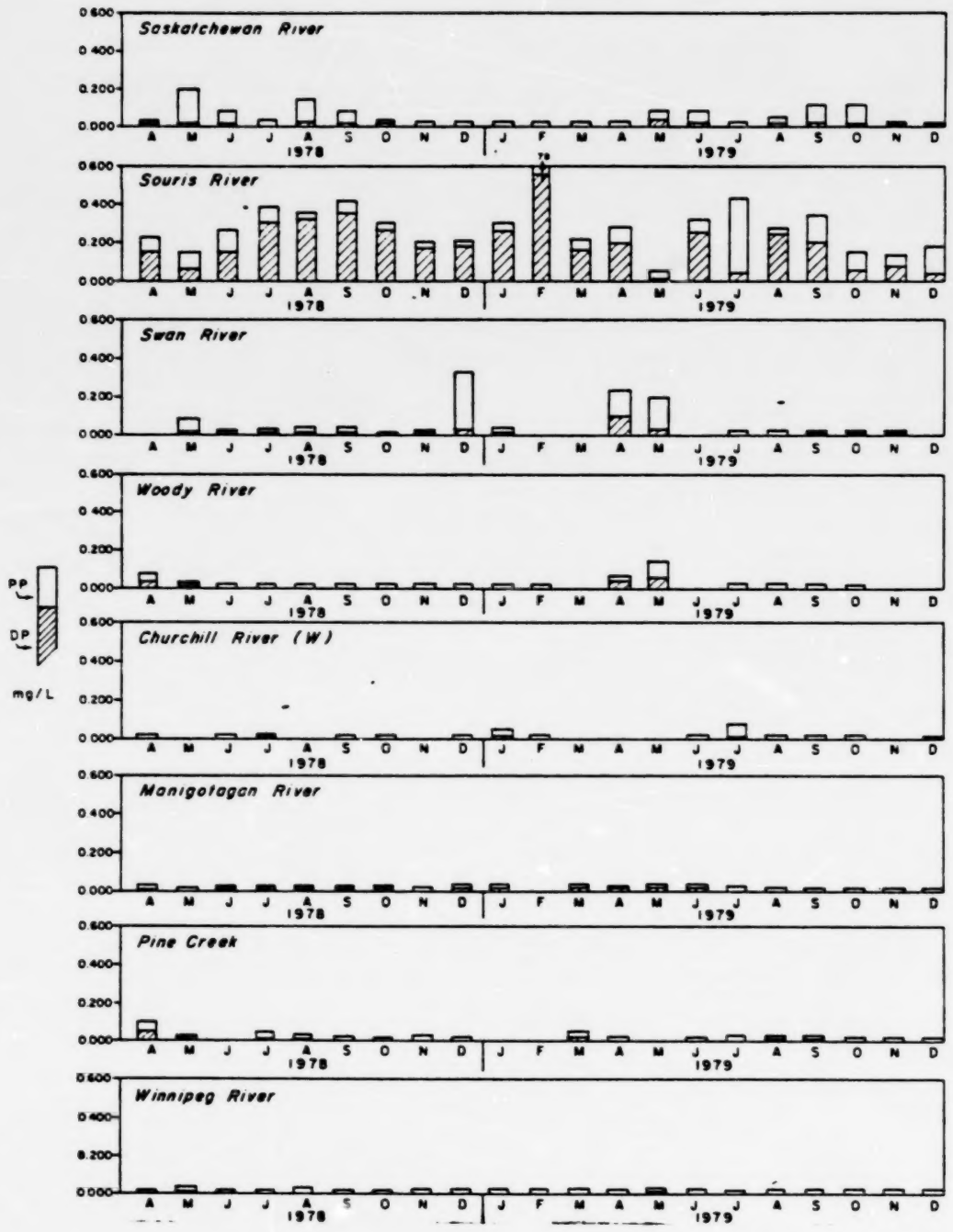


Figure 11 (continued).



The nitrogen speciation data are presented monthly in Figure 12. The previously noted dominance of DN is quite evident, however, some seasonal effects are apparent. As would be expected, PN frequently dominates or at least increases substantially in proportion during the spring melt (e.g. Assiniboine River (April, 1979); Pembina River (April, 1978 and 1979); Qu'Appelle River (April, 1978 and 1979)). There are frequently summer months when PN increases in proportion as well (e.g., Pipestone Creek (June, July, 1978); Qu'Appelle River, (July, 1979); Saskatchewan River (July, August and September, 1978 and 1979)). Particularly interesting is the monthly species distribution for the Red River. Although the summary statistics (Table 6) indicate the predominance of DN (61% of TN), it is evident that this statistic is highly affected by the spring and early summer data, for during the fall and winter, PN is clearly the dominant species. The rivers in the northern part of the province show little variability from month to month and are consistently dominated by DN.

(c) Organic Carbon Species

The organic carbon content of the rivers of Manitoba are quite clearly dominated by the dissolved species. As can be seen in Table 6, the range of DOC as a percentage of TOC for the rivers of the Palaeozoic-Mesozoic Region is from 69 to 98% for the Pembina and Overflowing Rivers, respectively. All of the rivers in the Pre-Cambrian Region of the province show 90% or more DOC. The monthly data plotted in Figure 13 generally illustrate the dominance of DOC year round, although the Pembina River shows a tendency for higher POC in the spring while the Red River has increased proportions of POC during the summer months.

Figure 12. Monthly Nitrogen Species Partitionings for Selected Rivers, 1978 and 1979.

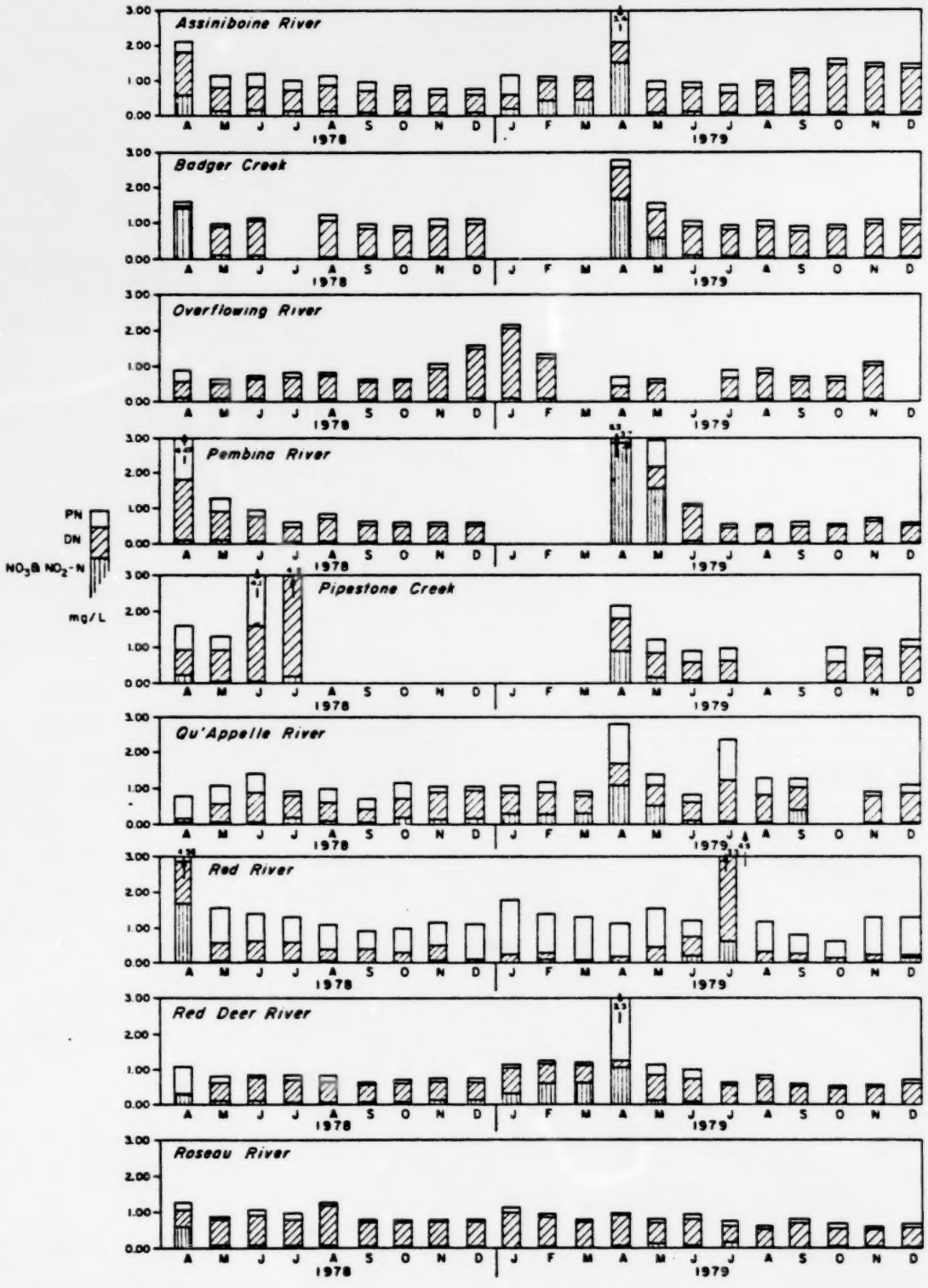


Figure 12 (continued).

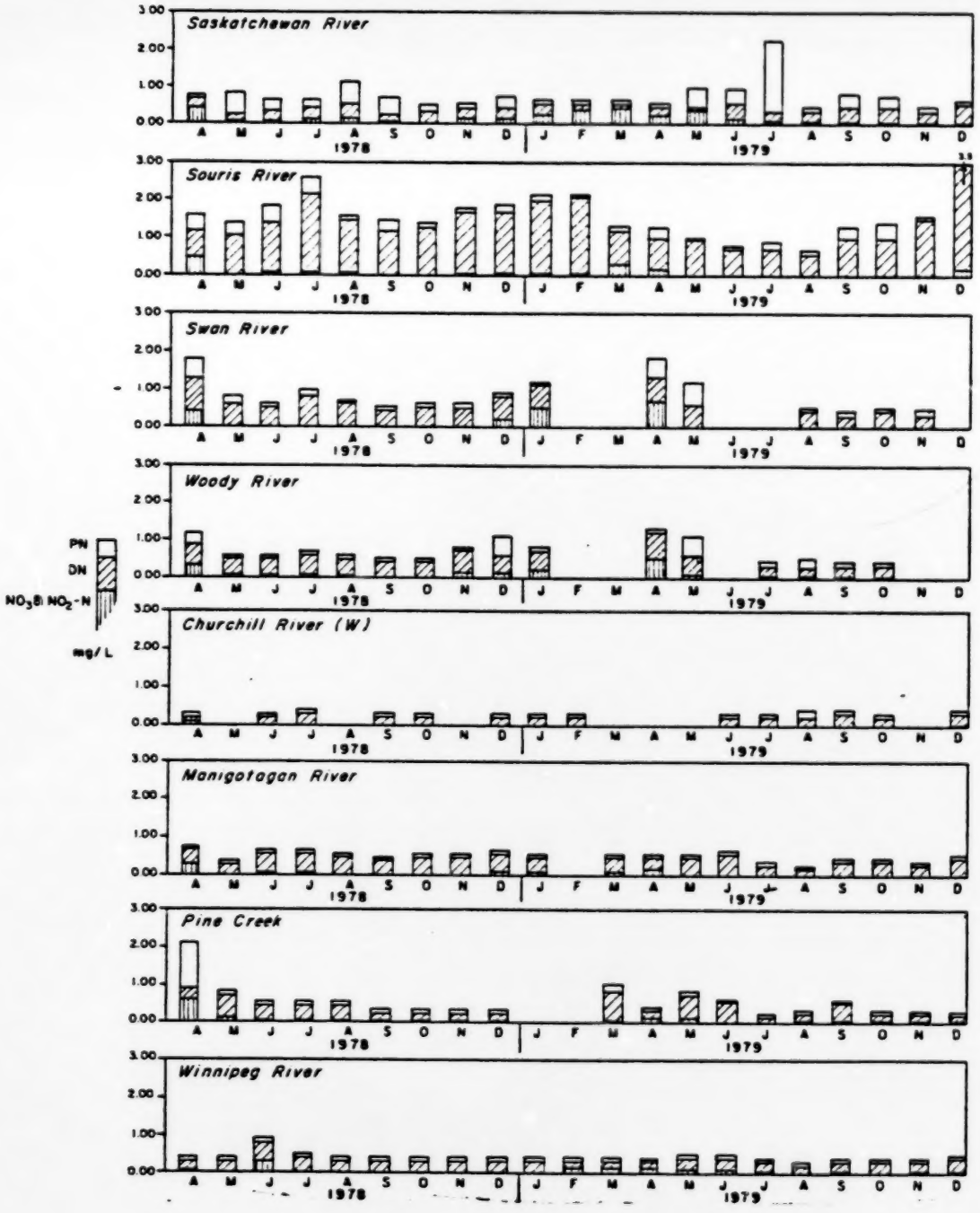


Figure 13. Monthly Organic Carbon Species Partitionings for Selected Rivers, 1978 and 1979.

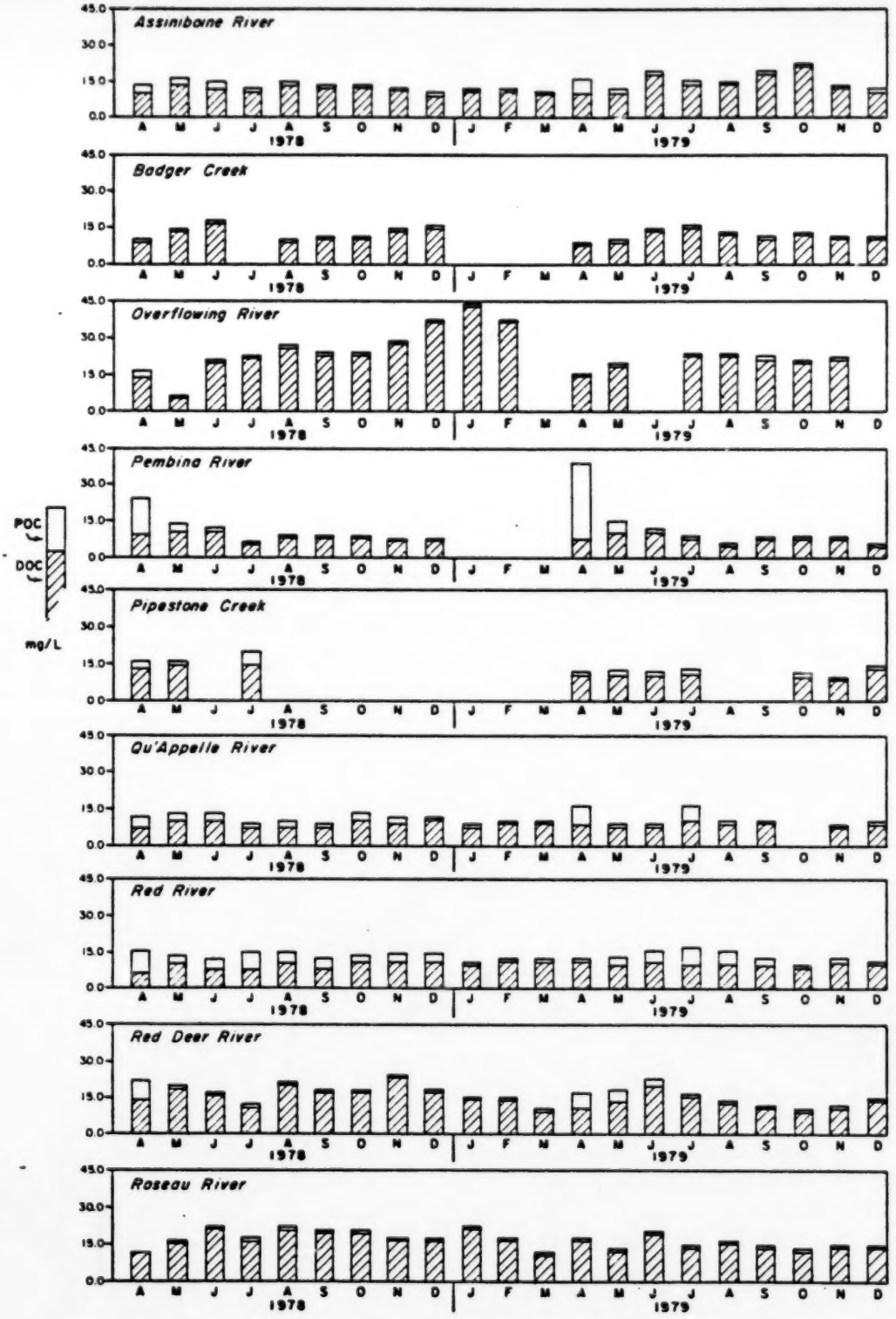
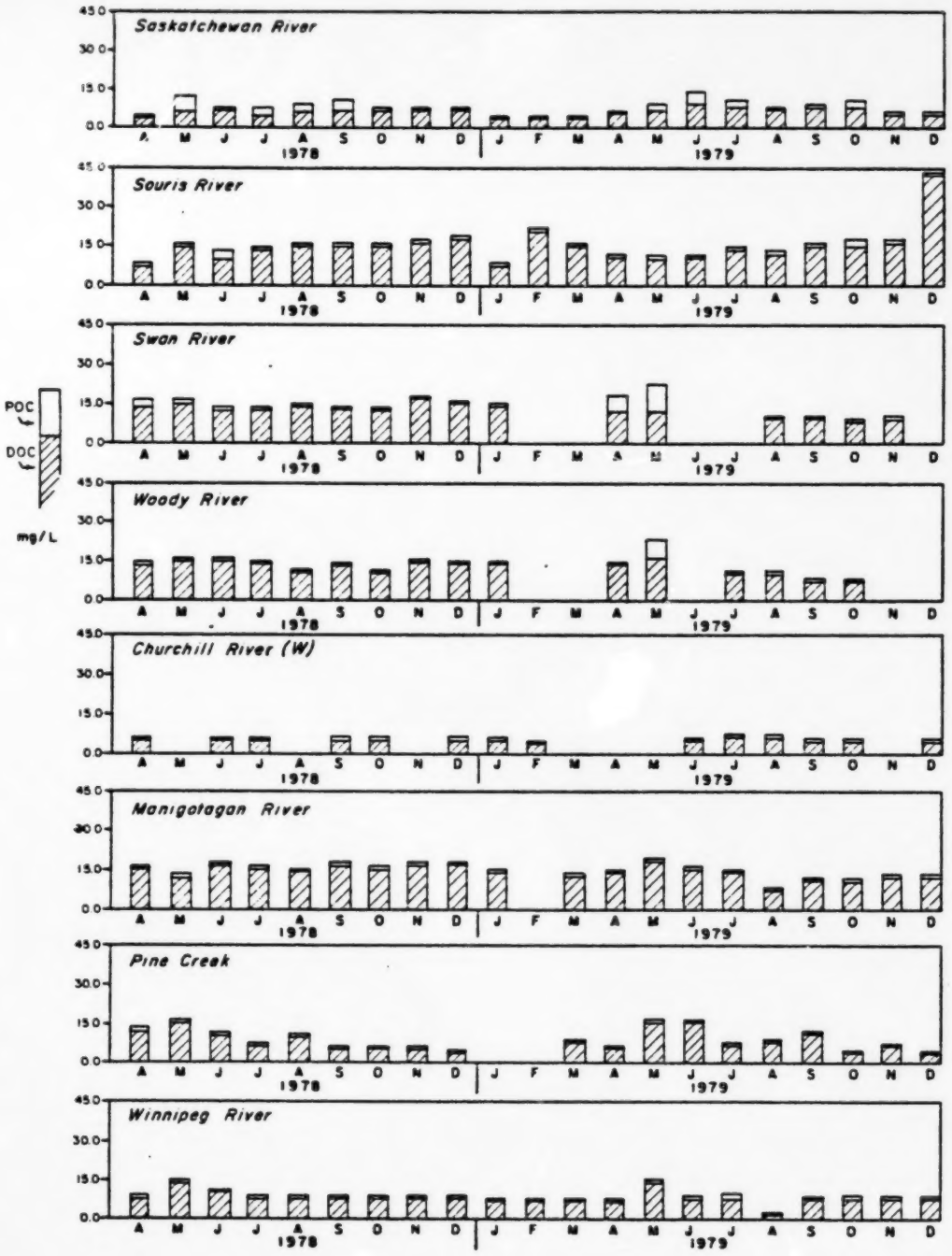


Figure 13. (continued).



SUMMARY AND CONCLUSIONS

Spatial patterns and annual cycles of phosphorus, nitrogen and organic carbon concentration data for the Manitoba boundary waters for the years 1970 to 1979 have been summarized. As well, the nutrient species data available for each of these sites for 1978 and 1979 have been considered. As appropriate, the observed patterns and cycles have been elaborated upon in the context of drainage basin characteristics in an attempt to evaluate these data and present them in a manner which will extend the basic understanding of surface water quality in the province of Manitoba to a wide audience.

The mean annual concentrations of the parameters varies greatly among sites. Nevertheless, the river systems generally partition into two main regions; the Palaeozoic-Mesozoic Region generally characterized by highly productive agricultural lands and the Pre-Cambrian Region consisting of shallow soils, bogs and forests in the northern and eastern part of the province. The former is generally characterized by higher concentrations of TN, TP and TOC. Seasonal variability is also much greater in the Palaeozoic-Mesozoic Region than in the rivers of the Pre-Cambrian Region, although the sample frequency discrepancies could have an important bias in these cases. The rivers of the Palaeozoic- Mesozoic Region appear to be greatly affected by annual variations in flow and precipitation. These systems are likely more susceptible to low flows due to the tendency for decreased annual precipitation from east to southwest and the reduced natural storage of the generally smaller southern watersheds. The response to flow variability is not consistent among the rivers.

Water quality objectives are used widely for assessing the quality of surface waters. Most rivers of the Palaeozoic-Mesozoic Region exceed the USEPA (1977) objective for TP of 0.05 mg/L. All the rivers of this region except for the Woody and Saskatchewan Rivers exceed the PPWB (1983) TN objective of 1.0 mg/L.

Loadings of nutrients to downstream lakes and reservoirs are frequently of greater concern to the protection of surface waters than simply nutrient concentrations. The loadings generated by these data are at best diagnostic and should not be assumed to be any more than approximations of the absolute nutrient loadings. The regional characterizations are no longer maintained by the nutrient loads due to the dominance of flow in the larger river systems particularly in the northern part of the province. Most noteworthy is the Saskatchewan River, which, although having relatively low nutrient concentrations for a river of the Palaeozoic-Mesozoic Region, accounts for about 30% of the TP and TN loads into the province and 20% of the TOC loading.

Brunskill (1974) observed that the southern portion of Lake Winnipeg is approaching an eutrophic state. However, the impact of the river systems draining to this part of Lake Winnipeg cannot be fully assessed due to the remoteness of these sampling sites from the lake.

Rivers of the Pre-Cambrian Region with adequate data show low concentrations and a lack of variability in TP, TN and TOC concentrations. Although far from consistent for all rivers of the Palaeozoic-Mesozoic Region, there is a tendency for: (i) TP to peak the month before or the same month as the high flows; (ii) TN to peak during late winter, decline during the spring and summer and increase again in the fall; and (iii) TOC to be generally uniform throughout the year or to peak in the spring and/or fall. The interaction of a number of hydrophysical factors accounting for higher instream flows in association with overland runoff during the spring would account for the spring TP highs. On the other hand, TN peaks during the winter when ground water as base flow is comprising the major portion, if not all, of the instream flow. The TOC cycle is related to the availability of allocthonous organic matter to the river system.

The partitioning of total nutrients between dissolved and particulate species in part addresses the nutrient availability question. The

biological availability of the particulate species has not been addressed. Since species data are limited to only 1978 and 1979, the pattern observed should be accepted cautiously. TDN ranges from 58 to 91% and from 74 to 89% of TDN in the Palaeozoic-Mesozoic and Pre-Cambrian regions, respectively. The partitioning of TP is much more complex, with PP dominating annually in the northern rivers while TDP ranges from 28% to 71% of TP in the rivers of the Palaeozoic-Mesozoic Region. As would be expected, consideration of monthly samples for these systems generally indicates the dominance of PP during the spring freshette.

DOC in all rivers dominates the total organic carbon concentration with the lowest DOC and POC ratio noted for the Red and Saskatchewan Rivers.

An evaluation of trends has not been attempted for these sites. This would require more intensive assessment of the annual (e.g. droughts) and seasonal variability in weather conditions as well as the variability of the data base among sites and between years.

Addition of data collected within the province by non-federal agencies would extend this interpretation, but would complicate the exercise particularly in the area of analytical method comparability. More importantly, although the drainage basin concept has been promulgated throughout the report, additional WQB data for many of these interjurisdictional systems (i.e. within Saskatchewan and Alberta) have not been included. These data should be the basis of another report on nutrients in Canadian plains river systems.

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